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Sewage Research

DIGESTION OF GARBAGE WITH SEWAGE SLUDGE*

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The disposal of garbage with sewage sludge is not an entirely new problem but the available data were considered insufficient to answer the important questions necessary before such a venture could be undertaken at the Indianapolis Sewage Treatment Plant.

The first experiments conducted in March, 1934, were on batch quantities. These tests indicated that garbage could be digested satisfactorily with sewage sludge and the results were of sufficient importance to indicate the necessity for further study of gas production, tank capacity needed and rate of destruction of organic material. The information gained from the early experiments also suggested the necessity of conducting further tests which would duplicate plant operation.

It was decided that the digestion tanks should be operated upon a daily charge and draw schedule. The charges were to be in proportion to the relative amounts of wastes received at the sewage and garbage plants, as shown by available data of past years. The amounts of sewage solids were 900 pounds of primary sludge and 1700 pounds of activated sludge per million gallons of sewage. The sewage flow was 50 million gallons per day. The quantity of green garbage was 100 tons per day. Chargings to the tanks were maintained upon such a schedule until the city's garbage was being ground and put into the sewage. After this the chargings were based upon the actual amounts of daily sludge production.

The tanks used were made from 5-gallon cream cans, inverted as shown in Figure 1. The inlet for charging was submerged below the liquor level of the tank to make a proper seal. A glass strip was built into the side of the tank for observation of the contents. Taps were placed throughout the depth of the tank for withdrawal of supernatant liquor. The stirring mechanism was built on the principle of a churn dasher, suitable modifications being made to prevent the loss of gas. Sludge was withdrawn through a ¾-inch cock in the bottom of the tank. From the gas vent a line led to an 8-liter gasometer.

The tanks were kept at 85° F., in an insulated water bath, which was checked each hour and controlled with steam.

The stirring of the tank was performed manually. At the start of the tests the agitation was once every day. It was soon found that this was insufficient to keep down the floating material, and when the

* Presented Before the Eighth Annual Convention of the Central States Sewage Works Association, Urbana, Ill., Oct. 25, 1935.

higher rates of charging were reached it was found necessary to agitate once every four hours.

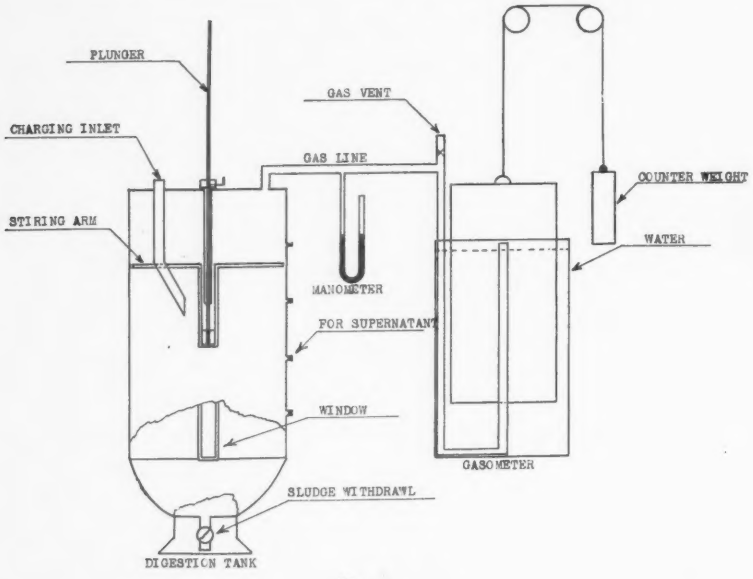

FIG. 1.

Chemical analyses were made on all materials charged and withdrawn. The determinations for solids, ash, total organic nitrogen, and petroleum-ether soluble were made upon the constituents of the charges, as well as upon the composited materials. In addition to these determinations, except for petroleum-ether soluble, B. O. D. was run upon the supernatant liquor.

TEST PERIOD WHEN SLUDGES AND GARBAGE WERE COLLECTED SEPARATELY

The tanks were charged with equal quantities of volatile solids. The ratios of primary and activated sludges were identical in both tanks.

The solids used for the chargings were obtained at the sewage disposal and garbage reduction plants. The catch sample of activated sludge was concentrated, before use, to an average of 4.50 per cent solids. The primary sludge was also a catch sample but it was used at the original average concentration of 5.96 per cent solids. The garbage was a sample taken from the garbage receiving pit at the reduction plant. This garbage was hand picked and it is believed to have been representative. The garbage was ground in a small household garbage grinder which required the addition of some water to facilitate grinding. During a period of the test there was no activated sludge available and so sludge from the plain aeration of sewage was used.

To eliminate as much laboratory work as possible, the chargings for several days were made up and stored in the refrigerator at 38° F.

The seeding sludge used in starting these tanks was obtained from the original digestion experiments. It was not a thoroughly digested sludge but it was thought advisable to use it rather than no seed at all.

At the outset of this work it was quite strongly believed that the garbage-sludge mixture would be much more difficult to digest than would the sludges alone. This explains many of the precautionary steps which were taken at the start.

Daily chargings to the two tanks were not started at the same time because it was thought that the garbage-sludge tank was not in quite as good condition as the control tank. It was but a few days until both tanks were taking equal charges of volatile solids at the initial established rate of 0.25 pounds of volatile solids per cubic foot of digester capacity per day.

At first, considerable difficulty was experienced with material getting into the gas lines. It was soon found that this condition was not caused by poorly digesting sludge. The difficulty was remedied by decreasing the volume of sludge from 14 to 12 liters and by maintaining a more frequent stirring schedule.

In charging the tanks every day it was necessary to remove some liquid before each charge. At first, supernatant was drawn whenever possible but later it was decided that, should Indianapolis resort to this fast rate of digestion, the sludge or supernatant would be discharged to the sludge lagoons and in that event it would be immaterial whether sludge or supernatant was drawn so long as the sludge in the digester was kept at a reasonable concentration. The contents of the tanks were thoroughly mixed before any sludge was drawn.

The gasometers were calibrated so that, when the gas pressure was equalized, they read in cubic centimeters.

Analyses of the sludges and garbage are given in Table I.

TABLE I

Material	Suspended Solids %	Volatile Solids %	Petroleum Ether Soluble %	Total Organic Nitrogen %
Activated Sludge	4.50	70.2	14.55	5.52
Primary Sludge	5.96	75.9	15.46	2.79
Garbage	11.40	94.6	24.06	2.94

The solids in the activated sludge are higher than can be obtained in actual practice. The garbage solids are low because of the water used in the grinding. The volatile matter in the activated sludge is higher than for several years previous when it had averaged 66 per cent. The petroleum-ether soluble and total organic nitrogen were also higher than the past averages. The primary sludge was about the same except for the grease, which was considerably higher than the average for past years, and the total organic nitrogen, which was lower.

There had been but little information gathered heretofore on the analysis of Indianapolis garbage. Some data obtained this past summer show that the grease was considerably lower than was found during the test under discussion. It is very likely that this was a seasonal difference rather than a possibility that representative garbage was not obtained for the digestion experiment.

An effort was made to charge both tanks with an equal volume of volatile solids each day. The volatile garbage solids added were 33 per cent of the total volatile solids added. The effect of the addition of the garbage can best be seen in Table II.

TABLE II.—*Showing Effect of Garbage on Charging Sludge*

Material	Suspended Solids %	Volatile Solids %	Petroleum Ether Soluble %	Total Organic Nitrogen %
Primary and Activated Sludges....	4.93	70.8	13.83	4.49
Primary, Activated, and Garbage...	5.50	77.1	17.16	4.21
Per Cent Change.....	11.6	9.0	24.1	6.2

It was quite impossible to charge the tanks with exactly equal volumes of volatile solids. At the end of the test the compiled data showed that the control tank had been charged with 8.2 per cent less volatile. It was also found that the control tank received 20.6 per cent more total organic nitrogen and 5.2 per cent less grease than the tank with the garbage-sludge mixture.

In consideration of the sludges drawn from the digestion tanks it is apparent that they were but slightly different, as can be seen from Table III.

TABLE III.—*Analysis of Digested Sludges*

Material	Suspended Solids %	Volatile Solids %	Petroleum Ether Soluble %	Total Organic Nitrogen %
Primary and Activated Sludges....	3.35	62.4	6.45	3.99
Primary, Activated, and Garbage...	3.44	63.7	6.46	4.10

Though the drawing of supernatant liquor was not regular practice, a summation of the data available has been made and is given in Table IV.

TABLE IV.—*Analysis of Supernatant Liquor*

Materials	Total Solids P.P.M.	Volatile Solids P.P.M.	Total Organic Nitrogen P.P.M.	B.O.D. 5-day P.P.M.
Primary and Activated.....	5,460	2,439	1,109	1,283
Primary, Activated and Garbage...	6,909	4,809	949	1,310

The supernatant liquor from the garbage-sludge mixture was some stronger, except for the nitrogen, than the supernatant from the sludge alone.

The losses taking place in the digestion units were calculated. All materials entering and drawn from the tanks were weighed, with as much accuracy as possible. A comparison of the losses in the two units is given in Table V.

The losses of petroleum ether soluble are excessive because they do not account for the grease lost in the supernatant liquor.

TABLE V.—*Losses During Digestion and Digestion Period*

Test	Volatile Solids %	Total Organic Nitrogen %	Petroleum Ether Soluble %	Digestion Period Days
Primary, Activated	45.3	38.5	70.1*	6.98
Primary, Activated, and Garbage	59.9	48.6	82.1*	8.80
When Garbage was being Added to Sewage	38.9	25.9	63.1*	3.96

* Grease lost in supernatant not accounted for in this computation.

Rate of gas production is an important factor in the digestion of garbage with sewage solids. It is believed that the most accurate method of rating gas production is cubic centimeters of gas per gram of volatile solids added. On this basis of comparison the garbage-sludge mixture produced 562 c.c. and the sludge 382 c.c. The averages of the results of 47 analyses made on each gas during the test are quite similar. These results are shown in Table VI.

TABLE VI.—*Comparison of Gases Produced*

Tank	CO_2 %	Other Gases %
Primary, Activated	30.8	69.2
Primary, Activated, and Garbage	32.7	67.3

The quantity of gas produced per gram of volatile garbage solids is very interesting. To arrive at such a figure with the data at hand it was necessary to make one assumption and do some calculating. The assumption made was that the primary and activated sludges, when mixed with garbage, produce the same amount of gas and at the same rate as they do when digested alone.

The calculations show that 963 c.c. of gas was produced per gram of volatile garbage, a quantity 2.52 times as much as obtained for sludge alone. This figure may be high because the detention time in the garbage-sludge tank was, on an average, 1.82 days longer than in the control tank, and also, the assumption stated above may not be a fact. The digestion periods are compared in Table VII.

TABLE VII.—*Detention Period, Days*

Tank	Average	Maximum	Minimum
Primary, Activated	6.98	11.8	4.5
Primary, Activated, and Garbage	8.80	12.0	5.7
Difference	1.82	0.2	1.2

The reason for the difference in digestion time was that an effort was being made to charge both tanks with an equal amount of volatile solids. The concentration of volatile solids was higher in the garbage-sludge mixture. The charge of smaller volume resulted in the longer detention period. A graph (Fig. 2) showing the relation of cubic

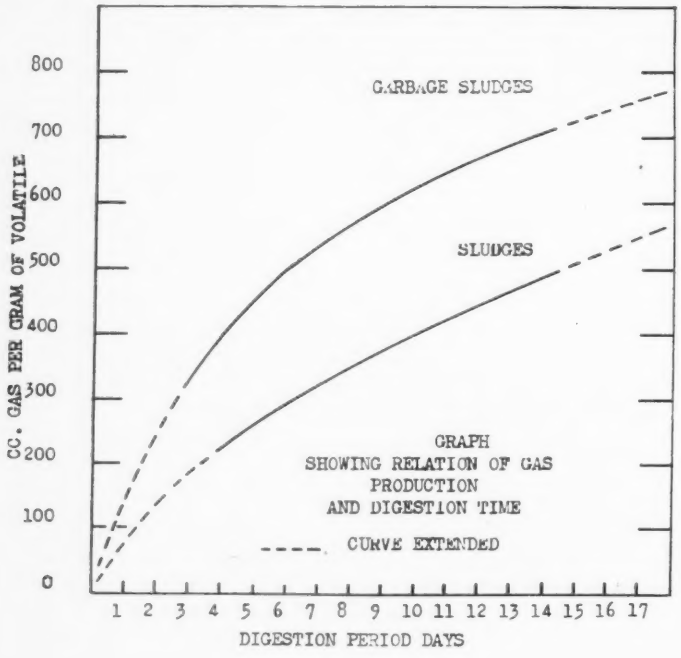

FIG. 2.

centimeters of gas per gram of volatile solids charged indicates that, for the same detention period, considerably more gas was produced by the garbage-sludge unit than by the control. This curve indicates that the large amount of gas produced in the garbage-sludge tank was not due to the increased detention time. The quantity of sludge in the garbage-sludge tank was never more than that in the control, so the high gas production could not be attributed to an excessive amount of sludge solids.

The quantities of volatile solids which were handled per cubic foot of tank space have been computed. The rates of addition were started

at 0.244 pounds per cubic foot per day and then were gradually increased. The range covered can be seen from Table VIII.

TABLE VIII.—*Pounds of Volatile Added per Cu. Ft. of Tank Capacity per Day*

Tank	Average	Maximum	Minimum
Primary, Activated	0.308	0.495	0.244
Primary, Activated, Garbage	0.293	0.396	0.239

At no time did the units appear to be overworked and there is no reason to believe that the garbage-sludge unit could not take as heavy a load as the control unit.

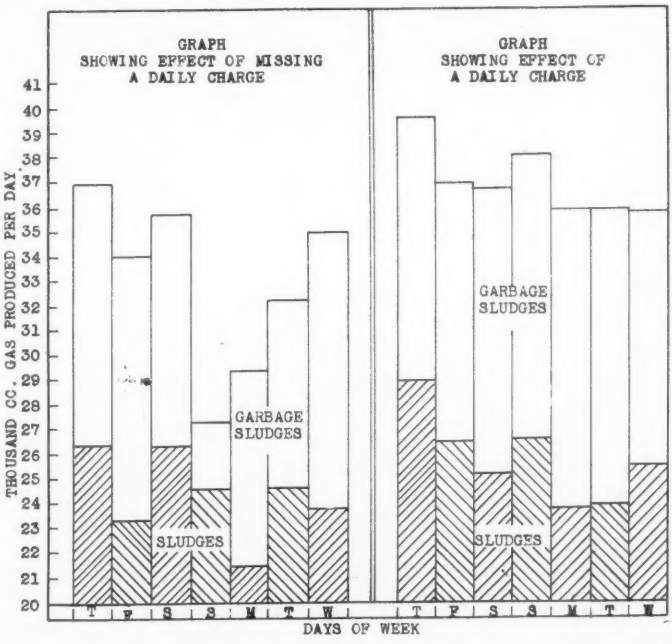

FIG. 3.

During a part of the test period, the digesters were charged every day and for the remaining time they were charged every day except Sunday. A glance at the daily data shows that there was a marked effect on the gas production when a charge was missed. A graph (Fig. 3) of the daily gas production of the garbage-sludge unit, when no charge was added on Sunday, shows that the gas produced on Sunday was about 24 per cent less than on Saturday. The decrease in gas production is noticeable at once in the case of the garbage-sludge mixture, while in the case of sludge alone the maximum loss does not appear until the second day after failure to charge. It is also to be noted that the recovery to maximum gas production was not immediate after the

charging was resumed. In fact, it took about four days to get back to normal. The recovery of maximum gas production from the sludge tank was not in steps as was that from the garbage-sludge tank. It was also noticed that there was a second low production which appeared on Friday. There appears to be some cycle in the digestion process which reflects the effect of failure to charge on Sunday in the following Friday's gas production. This peculiarity was observed in both tanks. The second part of Fig. 3 refers to similar periods, except that the tanks were charged every day; it can be seen that there are no great irregularities as were observed when charges were not made on Sunday.

The relation of dry garbage solids to suspended sewage solids received at the plants has been about the same for the past five years, as can be seen from Table IX.

TABLE IX.—*Relation of Garbage Solids to Sewage Suspended Solids Received at the Disposal Plants*

Year	Garbage, Per Cent of Sewage Solids	Year	Garbage, Per Cent of Sewage Solids
1929	16	1932	18
1930	16	1933	16
1931	17	1934	16

The percentage of garbage solids might be expected to be somewhat higher in a city where industrial wastes are of less magnitude than in Indianapolis. The equivalent population of Indianapolis is about 164 per cent of the estimated connected population, which was 345,000 in 1934.

TEST PERIOD WHEN GARBAGE WAS BEING GROUND AND PUT INTO SEWAGE

On May 1, 1935, failure of equipment at the garbage reduction plant made it necessary to resort to some other method of garbage disposal. It was decided to attempt to grind the garbage and add it to the raw sewage. After this date, all sewage sludge contained garbage and it was impossible to carry a control. Both digesters were to be charged with primary (which contained garbage) and activated sludges on the basis of the total pumpage of each sludge. The sludges charged were composited samples taken over a 24-hour period.

The average results of the analyses of materials charged and withdrawn are given in Table X. The results for the two tanks were almost identical so that it is advisable to consider them as one. It is of interest to note that the nitrogen is higher in the digested sludge than in the raw, due to the fact that the percentage loss of nitrogen is less than for the solids. The losses in the digestion process are functions of length of digestion period and type of material digested. The losses during the first part of the experimental work were considerable higher than toward the end as may be seen by reference to Table V, which shows losses and digestion periods.

TABLE X.—*Analysis of Charged and Digested Materials*

Material	Suspended Solids %	Volatile Solids %	Total Organic Nitrogen %	Petroleum Ether Soluble %
Raw Sludges	3.72	68.58	3.68	10.06
Digested Sludges	3.29	60.10	3.85	5.24

The maximum detention period during this last test was 5.6 days and the minimum was 3.5 days.

The gas produced during this period was 429 c.c. per gram of volatile solids added. There were 58 gas analyses made during the second test period; the average carbon dioxide content was 33.3 per cent. This closely approximates the analysis of the gas from the garbage-sludge mixture as given in Table VI.

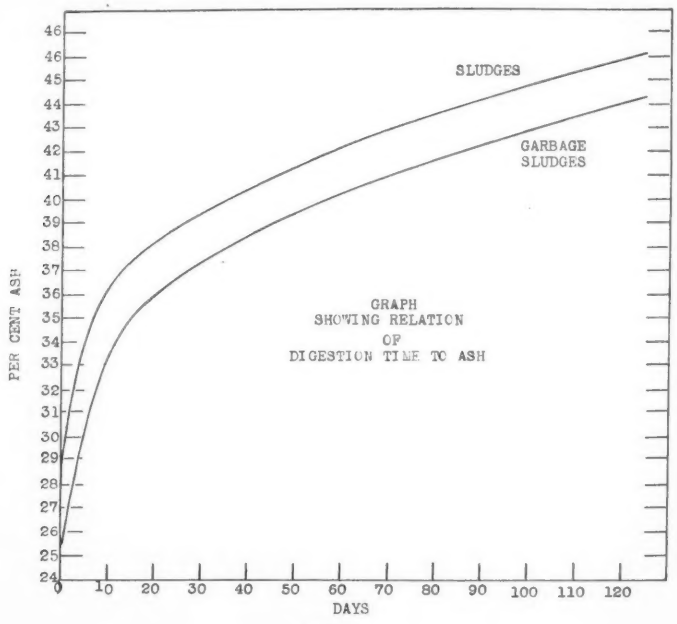

FIG. 4.

The average pounds of volatile solids handled per cubic foot of tank capacity per day during the last period was 0.422 as compared with 0.293 in the first test. The maximum rate obtained was 0.519 pounds per cu. ft. and this rate was maintained for about one month without upsetting the operation of the unit.

During the period when this test was run, an average of 82.3 tons of garbage was being ground and put into the sewage each week day. On a seven-day average this would be 70.5 tons per day. The average sewage flow for this period was 47.0 million gallons per day. Using

the average normal sludge productions of 900 pounds of primary and 1700 pounds of activated sludges per million gallons, and a moisture content of green garbage of 82 per cent, computations show that the garbage dry solids in the mixture amounted to 24 per cent. This should be compared with 26.2 per cent in the synthetically mixed sludge and garbage. It should be noted that this test did not extend into the peak garbage season.

The condition of the sludge removed from the digestion tanks is of importance. It may be said that the sludge removed throughout the investigation always had a good odor. During the latter period the digested sludges were not always as black as well digested sludge.

The rate of ash increase is shown in Fig. 4. Sludges were composited, held at atmospheric temperature, and analyzed occasionally throughout a period of 120 days. It can be seen that the rate of ash increase is the same whether or not garbage is present in the sludge.

For a short period during the first part of the test work it was impossible to obtain any activated sludge. This made it necessary to resort to the use of aerated sewage sludge instead. This material was handled in the digesters with equal ease. It is interesting to note that when these solids were used the rate of gas production increased and when they were again replaced by activated sludge the rate decreased. It is a fact that there is more grease in the aerated sewage sludge than in the activated sludge and this excess grease is believed to be one of the reasons for the increased rate of gas production.

Conclusions

1. Daily charges of primary sludge, activated sludge, and garbage, in which the volatile content of garbage solids was 33 per cent of the total volatile solids, digested for nine days at 85° F., produced 562 c.c. of gas (CO_2 content 32.7 per cent) per gram of volatile added, with a resulting decrease in volatile solids of 59.9 per cent.

2. It is absolutely necessary to submerge the material which collects at the surface of the tank.

3. Digestion takes place at a more rapid rate when garbage is present in a sludge mixture than in sludge alone.

4. The quantity of gas produced per unit of volatile garbage solids is at least twice that produced from primary and activated sludges.

Acknowledgment

The author wishes to acknowledge the assistance of Mr. C. K. Calvert and Dr. A. M. Buswell for their suggestions and Mr. D. T. Sherow, Mr. R. K. Lewis, and Mr. D. O. Bender in making the many chemical analyses and aiding in compilation of the data.

EXPERIMENTS ON THE DIGESTION OF GARBAGE AND SEWAGE SOLIDS *

By F. H. Whitley, Jr.

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Digestion experiments at the University of Illinois have been made in small scale laboratory set-ups, in 55-gallon steel drums, and on a scale that approaches actual plant operating conditions.

The earliest digestion set-up consisted of 2.5 liter bottles as digestors and similar bottles for the collection of the gas formed during digestion. The first series of digestion bottles was set up by May, 1934, and before June 30, 1934, two more series of bottle experiments were in operation. Each series consisted of four to six digestion bottles, each bottle with a different mixture of garbage and sewage sludge. The composition of the mixtures in these bottles ranged from 38 per cent to 92 per cent garbage, on the basis of total dry solids in the garbage and sewage sludge. The bottles were used as closed digestors, with no additions or removals of solids or liquor.

The sludge used in these preliminary tests was solids settled out of the strictly domestic sewage of Champaign-Urbana. The garbage was waste food from household kitchens and a local restaurant. It consisted of cooked food in the form of table wastes and raw food wastes left from the preparation of meals. Green vegetables of all kinds, bread, fruit peelings, meat scraps, and potatoes were some of the components of the garbage. The contract for garbage delivery had as its chief specification the requirement that the garbage be fit to feed to hogs.

Grinding of the garbage prior to digestion was considered essential in order to obtain a mixture as homogenous as possible. Paper and other foreign materials were removed from the food wastes, which were then ground in an ordinary household food chopper. The food chopper was the largest household model available and was very satisfactory for the early tests, which required only a small amount of garbage.

The bottle tests of the spring of 1934 were ended before June 30, and analyses were made of the contents. The laboratory examination showed, among other things, that there was a great range in the pH of the mixtures, with the more acid results representing the bottles with the least gas production.

In the fall of 1934, larger containers were used for the digestors in addition to the small bottles first used. Steel drums of 55-gallon capacity were converted into digestors and were equipped with gasometers in order that gas production could be recorded. These barrel digestors were arranged so that additions to and removals from the mixture could be made, and so that samples could be taken when desired.

* Presented Before the Eighth Annual Convention of the Central States Sewage Works Association, Urbana, Ill., Oct. 25, 1935.

Bottles were set up in pairs for each barrel, each pair of bottles containing the same mixture as in the corresponding barrel. These bottle tests were set up to check the gas production and also to afford visual observation of the contents during digestion.

In the six barrels and corresponding pairs of bottles, garbage and sludge alone were digested, and also mixtures of 20% garbage with 80% sludge, to 80% garbage with 20% sludge. These ratios were on the basis of dry volatile solids in the garbage and sludge. Imhoff tank sludge which had just started digesting was drawn from one of our large Imhoff tanks and used as the sewage sludge. The garbage was fresh and was ground before being mixed with the sludge.

No consistent results in gas production were obtained in this series. The conditions of the run were very unfavorable; the bottles and barrels were set up in our testing plant, which was insufficiently heated. The low temperatures probably inhibited bacterial action.

In preparing garbage in batches sufficient for the barrel tests, it was found that the household food chopper was too small and could not turn out enough ground garbage for our tests. Grinders are made and are on the market, designed for the grinding and pulverization of garbage. After investigating the machines made especially for garbage, it was learned that the cost of even the smallest was too great for our funds. After several machines had been studied, a small grain grinder was purchased at a cost of $12.00. From the first trial the machine pulverized garbage better than the food chopper. Paper, rags, and meat skins clog the machine, but if they are removed a satisfactory pulpy product may be secured. One man can grind approximately 100 to 125 pounds of garbage per hour with this grain grinder.

In the spring of 1935 another series of barrels and bottles was started. Sludge used was of three types: Imhoff sludge which was partially digested, fresh sludge from a sedimentation tank, and fresh activated sludge. The sludges were not mixed, but were used separately with the garbage to test the digestion of garbage with various sludges. A mixture of 50% volatile sludge solids with 50% volatile garbage solids was used in each case. The finished mixtures varied from a very soupy consistency in the case of activated sludge to a mushy consistency with Imhoff sludge, the latter having about 90% moisture when placed in the digestors. Two barrels, with a corresponding pair of bottles, were set up for each of the three mixtures.

Very erratic results were obtained in this run. In one barrel of each pair, gas was produced, while no bacterial activity was apparent in the remaining three barrels. Laboratory analyses showed no distinct difference in the contents of the separate barrels of each pair. Each pair received identical treatment and care throughout the duration of the test. Before using the barrels, all were thoroughly cleaned and sterilized to be certain that none of the former contents were left to interfere with digestive activity. The temperature varied only a little from normal room temperature for the greater part of the test.

The pairs of bottles gave results that were far from the consistency expected from identical mixes.

These results indicated that single tests on such a small scale are worthless, on account of the great variation in character of garbage. For this reason our conclusions are based entirely on the results of the large-scale tests reported by Prof. Babbitt.

THE DOSING OF SEWAGE TANKS WITH GROUND GARBAGE *

By Harold E. Babbitt

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Garbage may be introduced into a tank in many different ways, dependent upon the construction of the tank, the manner of conveying garbage to the sewage treatment plant, the location of the grinding equipment and other factors. The method of handling garbage at the Indianapolis sewage treatment plant comprises grinding the garbage and dumping it into the sewer some distance above the treatment plant. The ground garbage is well mixed with the sewage before reaching the treatment plant, therefore the character of the plant influent is similar to that of a strong sewage containing fresh solids.

If the garbage grinding plant is at or near the sewage treatment plant, it is possible to introduce the garbage into the tank at the inlet end, either in slugs of solid matter or through some type of continuous feeding device. One outstanding difficulty with such a method of feeding, either intermittent or continuous, is the danger that a large portion of the garbage may float through the plant without treatment. Where Imhoff or two-story tanks are available it might be possible to introduce the garbage into the gas vents either intermittently or continuously or, if the tank were covered for the purpose of gas collection, to introduce the garbage through a trapped inlet, pushing it deeply into the digestion compartment.

If a sewage treatment plant is designed for separate sludge digestion and the garbage is ground at the plant, the ground garbage may be fed to the digestion tank either intermittently or continuously, similar to the method of feeding sludge, or if the garbage is added to the sewage before reaching the plant the settled sludge, which will include settleable particles of garbage, can be added intermittently or continuously to the separate digestion tank.

All of these methods of dosing tanks have been or are being tested at our plant with the exception of the last one mentioned, in which ground garbage is mixed with sewage at a point well above the sewage treatment plant, and the solids removed by sedimentation are transferred to the separate digestion tank.

It is to be noted that the tests at our testing plant fall into two classes; one series in small containers and the other in relatively large containers. The methods of dosing that have been studied have been applied only to the larger containers. The tests in the larger containers include:

* Presented Before the Eighth Annual Convention of the Central States Sewage Works Association, Urbana, Ill., Oct. 25, 1935.

1. The effect on an Imhoff tank, designed for the collection of gas, of the intermittent dumping of ground garbage into the influent end of the flowing-through compartment.
2. The effect on an Imhoff tank, designed for the collection of gas, of the intermittent dumping of ground garbage into the deeper regions of the digestion compartment.
3. The effect on an Imhoff tank, with open gas vents, of continuously introducing ground garbage, intimately mixed with sewage, into the influent end of the flowing-through compartment.
4. The effect on a two-story, constant-temperature, separate-sludge-digestion tank of introducing ground garbage and fresh sludge intermittently into the primary compartment of the tank.

At first thought it might seem unnecessary to study the effect of dumping batches of garbage into the influent end of the flowing-through compartment of an Imhoff tank. It is to be expected that quantities of the solid materials will float across the tank, being discharged, untreated, with the effluent, unless stopped by hanging baffles. The effect of hanging baffles would probably be to create an accumulation of an unsightly and odorous scum formed of putrefying solids. Our tests bore out these expectations. No laboratory control was necessary to show that quantities of solid matter floated across the tank to be discharged with the effluent, and the interposition of scum boards or hanging baffles served to collect scum behind the baffles without making any apparent improvement in the character of the effluent, which continued to be choked with solid particles which had been sucked under the surface baffle. The results of the test demonstrate the folly of attempting to dose any type of continuously flowing sedimentation tank with garbage in this manner.

If garbage is to be brought to the sewage treatment plant, there to be ground and fed into the tank, the next most obvious point to apply it to an Imhoff tank is to the gas vents so that it may sink into the digestion compartment before escaping through the effluent. One of our Imhoff tanks at the testing plant, with a capacity of approximately 15,000 gallons, was equipped to receive garbage through the gas collection dome. In order that a fair test of the results might be made, a "control" tank was constructed to duplicate the garbage-fed "test" tank; the two tanks being operated identically except that one received ground garbage and the other did not. All necessary observations on rate of dosing, rate of sewage flow, quality and quantity of sewage and garbage and of the effluents, were made physically and chemically on both tanks. The proportion of wet garbage solids to sewage was approximately one million gallons of sewage to one ton of wet garbage.

Feeding of the tank was accomplished by adding, in batches, about 100 to 150 pounds of wet, ground garbage into the digestion compartment through a 10-ft. length of 8-in. steel pipe. This pipe passed through the cover of the gas vent in the top of the digestion compartment and terminated about eight feet below the water surface and two to three feet below the slot in the flowing-through compartment. Just

below the lower end of the pipe a V-shaped tin baffle was placed to permit the garbage to fall into the digestion compartment and to prevent the escape of gas from the tank. When ready for dosing the cover on the upper end of the pipe was removed and the charge of garbage was pushed down the pipe with the aid of a long-handled, double plunger. Considerable strength was usually required to push the garbage dose into the tank.

Shortly after the commencement of operation the approach of trouble was indicated by a decrease of pH values and an increase in concentration of volatile acids. The amount of gas collected never equalled that generated in the "control" tank and the garbage gas was always lower in methane, as indicated by its inability to burn well or at times to ignite.

Some time before the conclusion of the 3-month test the contents of the tank receiving garbage turned very sour and the sludge rose from the bottom of the digestion compartment to produce a 10-ft. thickness of scum on the top of the scum chamber. The gas vents became clogged and the pressure of gas and liquid resulted in the collapse of the sides of the flowing-through compartment. After operation for about two months it became impossible to collect gas from the "test" tank because of the clogging of the gas domes, whereas no trouble was being experienced with the operation or the behavior of the "control" tank.

Upon opening the "test" tank after a 3-month period of operation no sludge was found in the sludge compartment, which was filled with a sour, vile-smelling milky liquid and a vile-smelling scum. The scum had the consistency of slush and contained recognizable particles of undigested garbage. Acid fermentation was in progress in the tank but the hydrolysis and gasification of organic matter through alkaline digestion was absent or inhibited to such an extent as to be negligible. No carefully controlled laboratory tests were required to demonstrate the impracticability of dosing an Imhoff tank in this manner.

Having demonstrated the expected failure of this method of dosing tanks, our next test, which is now in progress, was commenced. In this test we are simulating the conditions which would result from the dumping of ground garbage into a sewer and admitting the mixture of garbage, suspended in sewage, to the influent end of the flowing-through compartment of the two-story tank. Our procedure consists in preparing a watery suspension of the ground garbage solids and pouring the suspension approximately continuously into the influent of our test tank. The covers on the gas vents, wrecked in the previous test by the pressure of confined gas, have not been restored on the "test" tank. The "control" tank is being operated identically with the "test" tank except that it receives no garbage. The "test" tank receives the dose of ground garbage in the proportion of one ton of wet garbage solids per million gallons of sewage treated. At no time has the tank given indications of approaching difficulties in operation. The pH has remained near or slightly above 7.0, volatile acids are low,

there is active gasification, and practically no formation of scum; in fact the test tank has shown less scum than has accumulated on the "control" tank. Sludge is accumulating and is digesting at approximately the same rates in both tanks and there is every indication that the "test" tank is taking the load without undue strain. Visual observations indicate the production of a larger amount of gas in the "test" than in the "control" tank but, unfortunately, facilities have not been available for the collection of this gas.

Our "control" observations on the quality of the effluent show, however, that an appreciable amount of the garbage solids appear in the effluent and the B.O.D. of the effluent is higher than that of the influent. A fine-mesh screen has been placed in the effluent from the tanks to permit observation of the discharged solids. Pieces of skins of potatoes, citrus fruit, and other typical garbage solids are recognizable in the solids screened from the effluent of the "test" tank, indicating that they are floating through the flowing-through compartment. They appear in the effluent in such quantity and condition as to indicate that they would cause trouble in secondary treatment devices.

More data are desired under the method of operation to corroborate or vitiate these preliminary observations. Following the collection of satisfactory data under these conditions it is our intention to increase the rate of garbage dosing by stages until the limit of the ability of the tank to digest the garbage has been reached, as indicated by the souring of its contents or other obvious indices.

Another test, which has been under way for about four months, is a study of the effect on a two-story, two-stage, constant-temperature, separate-sludge-digestion tank of introducing ground garbage and fresh sludge intermittently into the primary compartment of the tank. The construction of the separate sludge digestion tank is similar to an Imhoff tank, the doses of solids being applied to the primary compartment. This would be called the flowing-through compartment in an Imhoff tank. It is presumed that light, floating particles, particularly grease, will be carried to the top of the primary compartment where acid fermentation will be concentrated. Materials digested in the primary compartment fall through the slot to pass through another stage of digestion in the secondary compartment. The idea of such an arrangement is that the materials in the primary compartment, being mainly grease and carbohydrates, will be subject to acid digestion. It is expected that accelerated digestion will be obtained by separating this acid stage from the alkaline stage in the secondary compartment. Thus the advantage of stage digestion may be enjoyed without the necessity of opening the tank to transfer material from one compartment to another.

Our procedure in operating the tank is to dose it about three times a week with a mixture of ground garbage and sludge collected in a plain sedimentation tank. The quantity of garbage amounts to approximately one ton of garbage per million gallons of sewage treated. The sewage and garbage solids settle simultaneously.

In order to assure the proper operation of the tank the liquid in the secondary compartment is constantly circulated by pumping the subnatant liquor from a point two to three feet below the top of the secondary compartment, through a centrifugal pump, and discharging it into the bottom of the secondary compartment. The temperature of the tank is held within one or two degrees of 90 deg. F. Gas is collected in separate gasometers from both the primary and from the secondary compartments. The digestion tank has been in operation for more than four months and is showing every indication of being able to carry the load successfully, as indicated by the pH and volatile acids in the two compartments, and the quantity and quality of gas collected. So far as can be determined, no sludge is accumulating in either compartment and no inordinate amount of scum is accumulating. It has been found necessary, however, to operate a stirring device which was installed for the purpose of breaking up any troublesome amount of scum which might accumulate under the gas vents. This stirring device consists of circular paddles which are turned by hand one or two revolutions once or twice a day.

A very large amount of gas has been accumulated, which is rich in methane, indicating satisfactory digestion of the solids. The fact that the tank is not filling with sludge indicates excellent hydrolysis and the fact that its pH is slightly above 7.0 and that the volatile acids are below about 50 p.p.m. in both compartments indicates desirable conditions for good digestion. The tank is apparently taking the load satisfactorily and is making valuable gas both in quality and in quantity.

It is to be noted that we have put about one ton of wet garbage and 77.5 cu. yd. of wet sludge into this tank and, at the present time, there is no accumulation of sludge in the tank. The solids content of the supernatant liquor in both the primary and secondary compartments have shown no trend either to increase or to decrease, since the test was started. Total solids remain at between 0.11 and 0.75 per cent. The tank seems to have reached a maximum rate of gas generation of approximately 14 cu. ft. of gas per pound of volatile solids added.

We expect to continue this test for one or two weeks, after which the rate of dosing with garbage will be increased in an attempt to discover the limit of load which can be applied. A record of solids added and removed is being maintained, so that a solids balance can be maintained, in order to discover the effect of gasification and hydrolysis.

It is expected also, at a later date, to use other kinds of sludge in the tank, such as activated sludge, chemical precipitation sludge, etc., and also to study the effect of higher temperatures on the rate of digestion in the tank and the limit of load which can be placed upon it. A further test will be attempted to determine the possibilities of putting unground garbage into the tank.

It is to be noted that the garbage which we are using is somewhat selected material since our grinder is too small to handle large bones and other large, hard particles. No tin cans nor pieces of wood,

crockery, broken glass, or similar articles are allowed to slip into the grinder.

As one result of the tests made so far it can be said with safety that such a tank can handle a load equivalent to one ton of garbage per million gallons of sewage treated.

The operation of the tank for a 4-month period at this load has shown excellent gasification, and no sludge accumulated in the digestion compartment. The supernatant liquor, which is discharged when a charge is added to the tank, is slightly alkaline, is not putrid, contains about 0.3 per cent solids, and has a 5-day, B.O.D. of 1,000 to 1,200 p.p.m.

The sludge problem has been minimized and the disposal of the garbage has been simplified.

DIFFUSER PLATE STUDIES *

By A. J. Beck

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The activated sludge process of sewage treatment depends upon a proper biological flora and sufficient dissolved oxygen to maintain aerobic conditions. Originally the oxygen concentration in a diffused air plant was maintained by blowing compressed air through perforated pipe located at the bottom of the aeration tank. The development of porous plates for aeration was an important advance in the art of sewage treatment by the diffused air process, because of the saving in air.

Porous diffuser plates were used in the activated sludge plant at San Marcos, Texas, as early as 1916, and at Houston, Texas, in 1917. These plates had a permeability rating of about 6 cu. ft. per plate per minute.

Milwaukee was one of the first large plants to use porous diffusers. The permeability of these plates purchased in 1920 was 9.0 to 12.9. Plates with a permeability of 10 to 12 were used at the Des Plaines River Treatment Works of the Sanitary District of Chicago, which was placed in operation in 1922. Diffuser plates with a permeability of 10.5 to 15.5 were used in the Indianapolis Activated Sludge Plant, which was placed in operation in May, 1925.

Early Tests

Experimental work on diffuser plates was carried on by the Sanitary District of Chicago at the Tannery Testing Station and the Des Plaines River Treatment Works, from 1922 to 1924, by S. I. Zack, R. J. Bushée and Warren E. Howland. As a result of these investigations, it was decided to purchase plates with a permeability of 11.7 to 18.5 for the North Side Plant. These plates were of higher permeability than any used up to that time and were practically as coarse as the manufacturer was able to furnish. After seven years of operation they are still giving very satisfactory service.

General Properties of Diffuser Plates

Diffuser plates available to-day are made of either silicon dioxide or aluminum oxide grains bound together into a porous mass by a ceramic binder. In manufacturing the plates, sufficient water is added to the mixture of grain and binder to form a damp mass which is pressed into a mold 12 inches square and 1 or 1½ inches thick. The molded plates are then dried after which they are vitrified at a temperature above 1000° C.

The pore space makes up 30 to 38 per cent of the volume of the

* Presented Before the Eighth Annual Convention of the Central States Sewage Works Association, Urbana, Ill., Oct. 25, 1935.

plate. The size of the pores is dependent upon the size or combination of sizes of grain used to mold the plate.

Diffuser plates in a 15-foot aeration tank are subject to a pressure of 940 lb. per square foot when the air supply is shut off. As a measure of their strength, plates at the factory are required to carry a total load of 1000 lbs. uniformly applied on a surface ½ inch wide extending across the plate on a centerline parallel to the supported edges. The plate is uniformly supported at two opposite edges on bearing surfaces ⅜ inch wide and 11 inches apart. This results in a safety factor of more than 4.

Alkalies and acids, except hydrofluoric, have no deleterious effect on diffuser plates at ordinary temperatures. Gradual change of temperature up to 900° C. is not injurous to plates.

Special Properties of Diffuser Plates Affecting Aeration Process

Diffuser plates are graded according to their capacity to pass air. This characteristic of a plate is called permeability. The permeability of a plate is the number of cubic feet * of free air at 70° F. and 10 to 25 per cent relative humidity which will pass through one square foot of plate area to atmosphere with a pressure of 2 inches of water under the plate, when the plate is tested dry at 70° F. The permeability of a plate is affected by the number and size of pores and the thickness of the plate. A plate 1½ inches thick must have either more pores of the same size or larger pores than a plate one inch thick, if the permeability of the two plates is the same.

The frictional resistance of a wet diffuser plate to the flow of air is termed pressure loss. The pressure loss at a given air rate varies inversely as the permeability. Plates of higher permeability have lower pressure loss. Low pressure loss is very desirable from an operating standpoint.

The size of grain used in manufacturing diffuser plates governs the pore size, which in turn determines the permeability and pressure loss.

The evenness of distribution of pores over the entire area of a plate is termed uniformity.

When all of a number of plates fastened in one plate container and supplied with air by a common air line pass approximately the same quantity of air the plates are said to give uniform distribution. Uniform distribution is desirable and this is especially true with the present trend to fewer rows of plates.

Description of Tests

This investigation was started in March, 1934, for the purpose of obtaining data for diffuser plate specifications for the Calumet Sewage Treatment Works Extensions and new Southwest Sewage Treatment Works.

* Air at the barometric pressure at which the test is made.

Permeability and Uniform Distribution

Late in 1932, 1500 diffuser plates were purchased from each of three manufacturers to replace the experimental plates in three aeration tanks at the North Side Works which had become completely clogged. Each tank is 34 feet wide and has 1440 plates arranged in four rows, two on either side of a center baffle wall. The original plan was to replace all the plates in the three tanks. However, at the time of installation, it was decided to replace only two rows, one row in each bay next to the baffle wall or a total of 720 plates in each tank.

After the plates were installed and the tanks were put into service it was found that one group of plates gave uniform distribution, while two groups gave non-uniform distribution. Pressure loss tests showed little difference in the pressure loss through the three kinds of plates.

At the North Side Plant, eighteen plates are fastened in each plate container, and the air is admitted at one end. This led to the thought that possibly the poor distribution was caused by pressure loss through the plate container.

The pressure loss through the plate containers was determined, and these results are presented in Table I.

Table I.—*Pressure Loss Through Plate Boxes*

Date	Cross-sectional Area in Square Inches	Air Rate in C.F.M. per Plate	Pressure Loss in Inches of Water
3/27/34	23	3.5	.13
		2.7	.05
		1.6	.03
5/1/35	23	4.3	.10
5/3/34	23	5.0	.08
5/4/34	23	3.0	.20
5/3/34	28	5.9	.04
5/7/34	28	1.6	.02

The test showed the pressure loss to be too low to explain the marked non-uniform distribution.

Some of the remaining plates were returned to the factories where accurate permeability tests showed the plates to be incorrectly rated.

Following the above tests, six sets of 36 plates each with permeabilities as follows were obtained from the manufacturers:

1—(66.0 — 67.0)	4—(38.6 — 41.5)
2—(52.0 — 53.5)	5—(58.3 — 61.5)
3—(40.1 — 40.8)	6—(36.0 — 37.0)

Each set was installed in a separate section in a tank with its own air supply and metering orifice. The plates were placed so that those of highest permeability were farthest from the air inlet.

When the tank was put into service all six sets of plates gave uniform distribution.

From these results it was concluded that in order to obtain uniform distribution it is necessary to have diffuser plates carefully rated, and

secondly that plates with a high permeability rating and low pressure loss will give uniform distribution.

Permeability and Bubble Size

Scouller and Watson [2] in a paper read before a meeting of the Institute of Sewage Purification in London in July, 1934, showed that oxygen is absorbed from air bubbles rising in de-aerated water. Scouller and Nixon [3] in a paper read before the Institute later in 1934 showed that the rate of solution of oxygen from air bubbles is directly proportioned to their surface area.

In connection with the tests on diffuser plates at the North Side Treatment Works the relation between the permeability of the plate and the size of the bubble produced was determined.

Diffuser plates made by three different manufacturers were tested. The average size of bubble given off by a diffuser plate was determined by photographing the bubbles against a background of Van Dyke cross-section paper with twenty divisions per inch. The cross-section paper was cemented to a piece of sheet metal to secure a plane surface. A wooden frame provided with grooves was used to hold the piece of sheet metal in a vertical position over the diffuser plate. A piece of glass was held parallel to and ½-inch from the cross-section paper by a second set of grooves to keep the bubbles in a vertical plane.

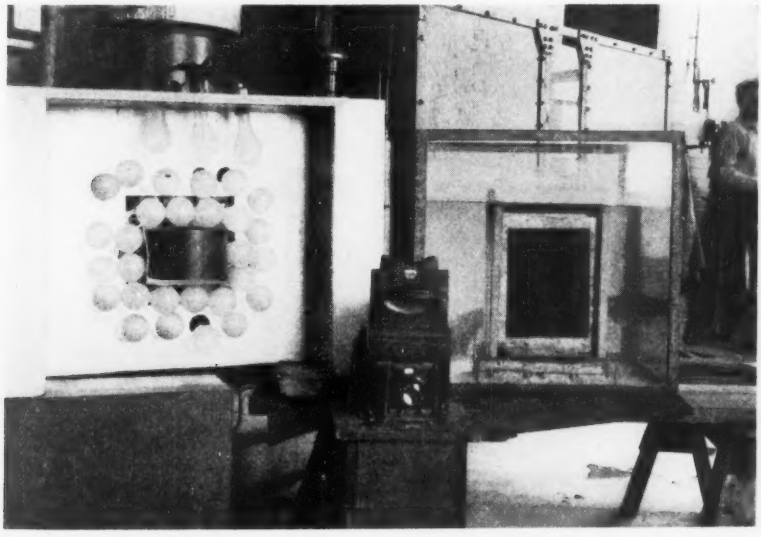

Fig. 1.—Bank of lights, camera, and apparatus used to obtain photograph of bubbles.

The diffuser plates used in the test were fastened into single concrete or sheet metal containers with Portland cement grout. Each plate was submerged to a depth of eighteen inches in a glass walled tank filled with water. Air was supplied to the plate container through a metering orifice.

An intense light was required to secure a normal exposure. During the summer months direct sunlight in conjunction with three mirrors was used to illuminate the bubbles. Later a bank of 30 photo flood lamps was used (Fig.1).

Photographs were taken using an air rate of 1.0 and 4.0 cu. ft. per min. per plate. Supersensitive panchromatic film was used with a lens opening of f:4.5, and an exposure time of 1/750 of a second.

Enlarged positives were made from the negatives, on a scale in which one inch of the cross-section paper was represented by two inches. The size of the individual bubbles was determined with the aid of a hand lens and the cross-section paper (Fig. 2). The diameter

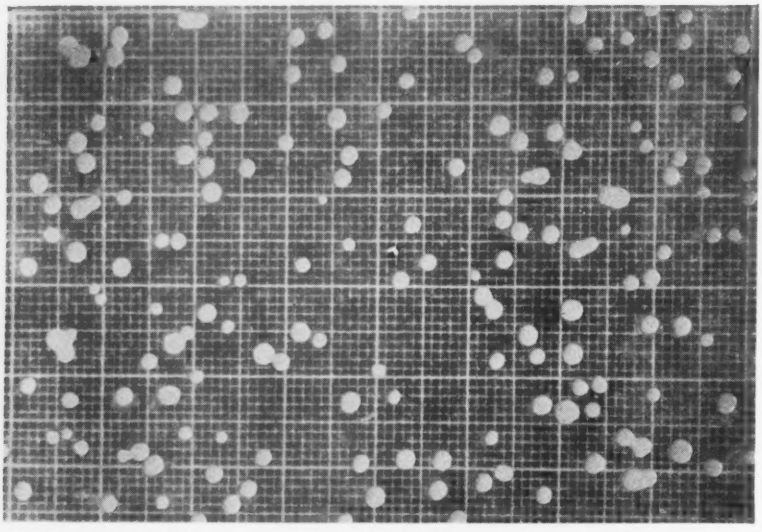

FIG. 2.—Air bubbles as measured with background of cross-section paper.

TABLE II.—*Method Used in Calculating Bubble Areas*

Diameter of Bubble in Inches	Volume of Bubble in Cu. In.	Total Volume, Cu. In.	Number of Bubbles of Each Size
.050	.000065	.000650	10
.055	.000087	.000435	5
.060	.000113	.000904	8
.065	.000143	.001144	8
.070	.000179	.000537	3
.075	.000221	.003536	16
.080	.000268	.002680	10
.090	.000381	.005334	14
.100	.000523	.005753	11
.110	.000697	.001394	2
.115	.000800	.003200	4
.120	.000905	.009905	1
Total		.026472	92

Average Volume .000288 Cu. In.
Average Diameter .0818 Inch
Number of Bubbles per 0.1 Cu. Ft. of Air 600,000
Surface Area per 0.1 Cu. Ft. of Air 87.5 Sq. Ft.

of all single bubbles with distinct margins in an area of 4 to 6 sq. inches was recorded, usually to the nearest 0.015 inch. The total volume represented by the bubbles recorded was next calculated. By dividing the total volume by the total number of bubbles, the average volume was obtained, from which the average surface area was calculated. From the average volume, the number of bubbles equal to 0.1 cubic foot of air was obtained and the total surface area of these bubbles was calculated. Diffuser plates were then compared on the basis of surface area of air bubbles resulting when 0.1 cu. ft. of air is diffused.

The method used in calculating the average bubble surface area is presented in Table II.

TABLE III.—*Area of Bubbles With Various Diffuser Plates*

Manufacturer	A									
Permeability	14–18		32.5		C–40		50		67	
Air rate in c.f.m. per plate	1	4	1	4	1	4	1	4	1	4
Total bubble area in sq. ft. resulting when 0.1 cu. ft. is diffused	96.0 102.7 94.2	72.7 74.1 86.5 96.0 100.4	75.0 85.4 88.8 77.6	81.8 85.6 80.1	82.2 82.0 79.9 72.2	73.3 80.0 81.6 77.7 73.3 75.9 81.2 74.1 71.8	76.4 80.1 78.7 74.2	67.0 68.5 79.7 77.6 81.7 77.9 80.0	72.7 77.1 92.2 82.0 87.2	91.3 83.7 76.3 78.1 76.2 87.2
Manufacturer	B									
Permeability	33		40.1		C–40		56		60	
Air rate in c.f.m. per plate	1	4	1	4	1	4	1	4	1	4
Total bubble area in sq. ft. resulting when 0.1 cu. ft. is diffused	84.1 84.6 77.6	83.0 84.8 93.7	103.0 93.1 93.6 84.6	82.5 83.8 86.7 84.6	91.7 96.2 104.4 85.2	85.1 87.2 88.0 95.2	81.3 79.5 71.6 74.9	83.1 81.7 84.3	79.6 86.8 80.1	74.1 75.6 68.5 68.3
Manufacturer	C									
Permeability	13.1		14–18		16		24		37	
Air rate in c.f.m. per plate	1	4	1	4	1	4	1	4	1	4
Total bubble area in sq. ft. resulting when 0.1 cu. ft. is diffused	81.0 96.5 92.4 89.9 92.2	99.8 96.0 88.0 70.9 85.4 85.3	75.7 92.3 85.6 85.2 95.2 91.2	71.2 107.6 79.7 87.8 74.3 85.1 84.5	84.5 95.7 90.0 106.9	76.7 81.0 87.6 97.2	92.6 97.7 84.6 103.8	78.7 91.7 77.1 87.8 81.8 84.9	71.3 80.0 94.4 91.2 82.5	79.1 82.6 83.5 70.2 77.3 73.9

Table III shows the results of the individual determination on fifteen plates of three manufacturers, (Fig. 3) at air rates of 1.0 and 4.0 cu. ft. per min. per plate. These results were used to obtain the averages given in Table IV.

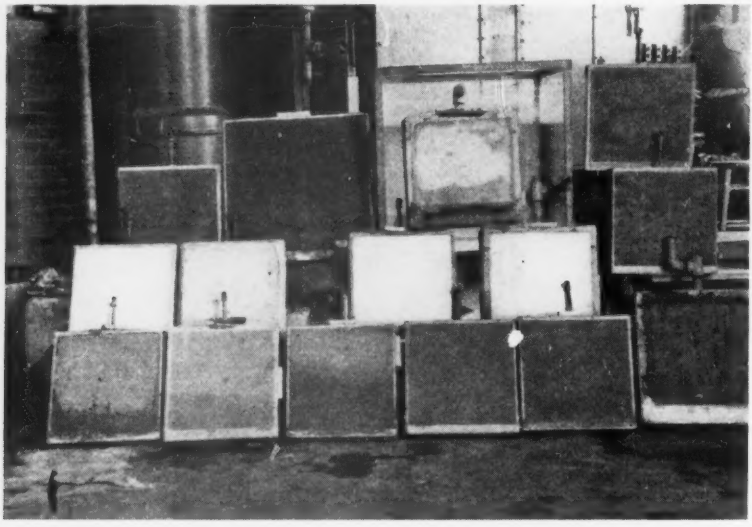

FIG. 3.—Fifteen plates from three manufacturers, as used in tests.

In general the results show that plates of higher permeability produce slightly lower bubble area per unit of air. Also slightly lower bubble area is produced at the higher air rate. The plate with a permeability of 67 under Manufacturer A is an exception. This was an experimental plate ¾-inch thick.

TABLE IV.—*Summary of the Average Bubble Areas Obtained From 0.1 Cu. Ft. of Air*

Manufacturer	Permeability	Bubble Area in Sq. Ft. from 0.1 Cu. Ft. of Air	
		1 c.f.m. per Plate	4 c.f.m. per Plate
A	14–18	98.0	86.2
A	32.5	81.5	81.5
A	C–40	79.2	76.4
A	50	77.9	75.8
A	67	81.9	82.8
B	33	86.2	81.9
B	C–40	94.3	88.9
B	40.1	93.8	84.2
B	56	76.4	82.8
B	60	81.9	71.8
C	13.1	90.0	86.7
C	14–18	87.5	84.2
C	16	93.8	85.4
C	24	94.3	83.4
C	37	83.4	77.9

From the results obtained it may be concluded that no great loss in efficiency can result by using plates with permeability rating up to 67.

Pressure Loss Increase with Operation

The pressure loss through diffuser plates increases with use. Pressure loss tests were made on plates in the aeration tanks at the North Side Treatment Works on August 2, 1929; December 23, 1931, and July 18, 1934. Figure 4 gives the results of these tests. The

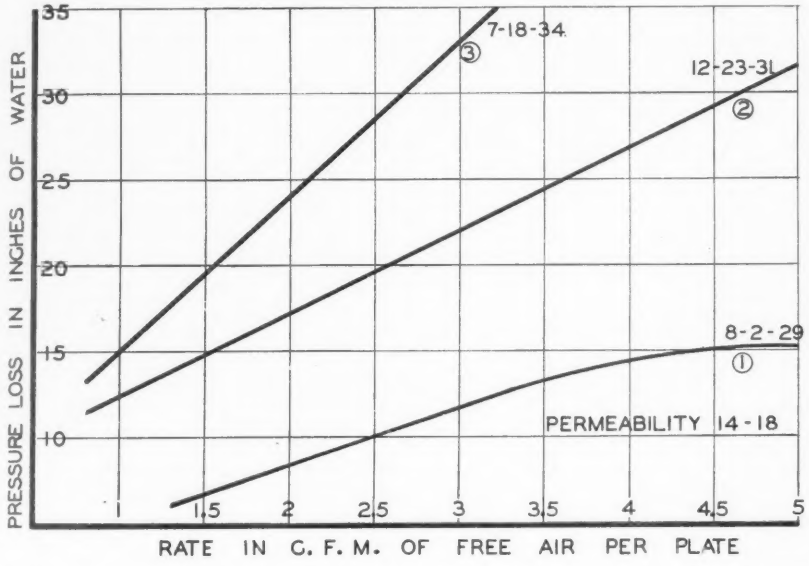

Fig. 4.—Results of tests on loss of pressure from 1929 to 1934. Low permeability. Air rate 1.0 cu. ft. per min. per plate.

increase in pressure loss for the first period was equal to a pressure of 8.6 inches of water at 2 cu. ft. of air per min. per plate, while the increase in the second period was equal to a pressure of only 6.8 inches of water, showing a slight decrease in the rate of clogging. The average operating air rate on these plates was 1 cu. ft. per min. per plate.

A test was made to determine the rate of increase in pressure loss, using plates with a permeability rating of 30.0 to 32.9. These plates were operated at an average rate of 2 cu. ft. per min. per plate. Figure 5 shows the results of pressure loss, tests made on July 19, 1934, and again on March 14, 1935. During eight months of operation the pressure loss increase at a rate of 2 cu. ft. per min. per plate was equal to a pressure of 1.6 inches of water.

During the latter part of 1934, one of the aeration tanks at the North Side Works was used to aerate return sludge. The pressure loss increased, in 69 days of operation, to a point where it was necessary to

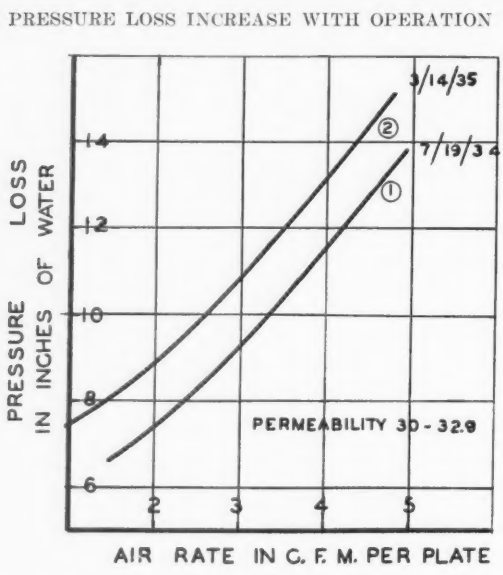

FIG. 5.—Results of tests on loss of pressure in plates of medium permeability, 1934 to 1935. Air rate 2.0 cu. ft. per min. per plate.

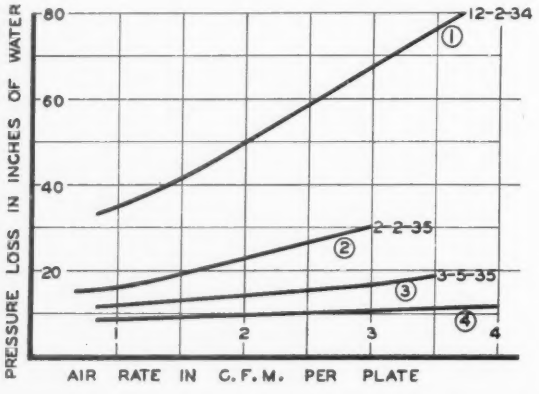

FIG. 6.—Loss of pressure in reaeration tank in 69 days, and decrease in pressure following aeration alone, and later treatment with nitric acid.

discontinue the test. Curve 1, Figure 6, shows the pressure loss after 69 days of operation. The tank was half filled with mixed liquor and aerated without addition of sewage from Dec. 21, 1934, to February 2, 1935, when a second pressure loss test was made. Curve 2, Figure 6, gives the result of this test. The pressure loss at 3 cu. ft. per min. per plate was reduced from 66 to 30 inches of water. It appears that after the food supply in the mixture was depleted the organisms attacked the material which had accumulated at the surface of the plate, thereby causing a marked reduction in pressure loss.

An examination of sections of clogged diffuser plates showed the clogging to be confined to the top surface to a depth of one-eighth inch. A few black specks of carbon were uniformly distributed throughout the plate.

Reducing Pressure Loss by Means of Oxidizing Agents

As the pressure loss through diffuser plates increases, the cost of compressing air also increases. Finally a point is reached where it becomes economical to replace the plate or find some means of reducing the pressure loss.

Roe [4] in a survey among those in charge of plants throughout the United States and Canada listed ten methods for cleaning plates in place and four methods for cleaning removed diffusers.

It is almost impossible to remove plates set with a 1:1 Portland cement grout, so an attempt was made to find a satisfactory method for cleaning plates in place. Nitric acid was the first agent tried.

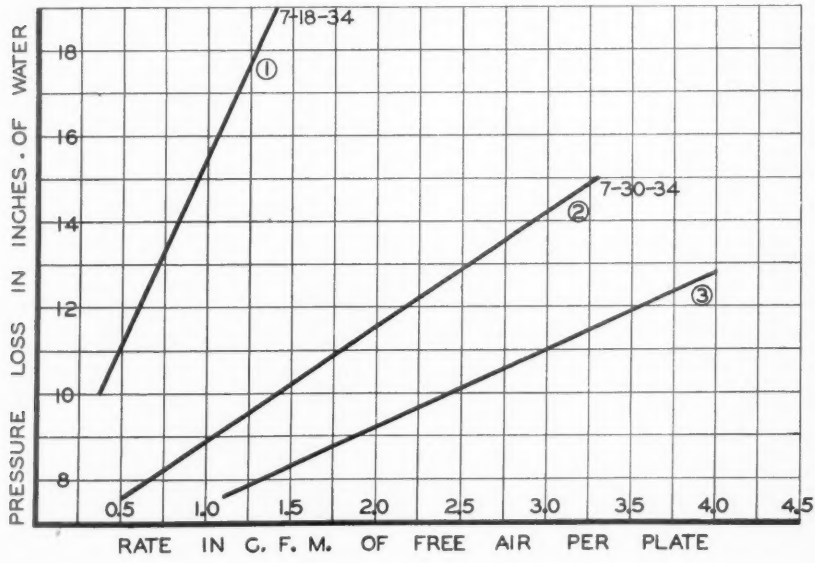

Fig. 7.—Results of tests on cleaning plates by means of sulphuric-chromic acid.

All the plates in one aeration tank, 1440 in number, were treated with 36° Bé. (50 per cent) nitric acid. It was necessary to do the work in two steps, because a preliminary treatment was required to destroy the comparatively dense top layers of organic matter before the plate would absorb much acid. One-half pint of acid was applied to each plate. Only sufficient acid to wet the plate was used for the first application and the remainder applied the following day. The result of pressure loss tests made before and after treatment are presented in Curves 1 and 2, Figure 7. A reduction in pressure loss of 12 inches of

water at 2 cu. ft. per min. per plate, resulted from the treatment. The cost of such treatment for labor and acid, at the time of the experiment, was about six cents per plate.

A test was made on the plates in another aeration tank using on each plate 100 c.c. of 66° Bé. (95 per cent) sulphuric acid containing 2 grams of sodium dichromate. The acid was applied in two doses with 43 hours between treatments. The results of pressure loss tests before and after treatment are given in Figure 6, Curves 2 and 3. The reduction in pressure loss by treatment with a mixture of sulphuric and chromic acid was equal to a pressure of 10 inches of water at 2 cu. ft. per min. per plate. Curve 4, Figure 6 and Curve 3, Figure 7, show the pressure loss of plates with a permeability of 30–32.9 after 8 months of operation. The cost was about the same as in the previous test with nitric acid.

Aged Portland cement grout removed from plates used at the North Side and Calumet Works was tested for resistance to both nitric acid and the the sulphuric chromic acid mixture. The former caused the grout to disintegrate rapidly, while the latter had little effect on it. This indicated that for plates set with Portland cement grout it is desirable to use the sulphuric chromic acid mixture for cleaning.

From the results of the test it was concluded that the life of the plates at the North Side Works could be extended to equal the life of the plant by means of acid oxidizing agents.

Factors Affecting the Permeability Test

The most important item in diffuser plate specifications is the permeability rating. The permeability test becomes increasingly important as plates of higher rating with corresponding lower pressure loss are specified. This is especially true when a number of plates are put in one plate holder.

Effect of Barometer on Permeability Test

Flow of fluids are of two types, viscous and turbulent. The type of flow is dependent upon the viscosity and density of the fluid and the velocity of flow.

In the case of viscous flow, the rate of flow is proportional to the difference in pressure, while under conditions of turbulent flow the rate is proportional to the square root of the pressure difference. Howe [5] found that the air passing through a diffuser plate was directly proportional to the pressure head. Howland, in an unpublished Sanitary District report (1924), found that straightline relationship existed between pressure drop and air flow per unit plate area, for submerged plates.

Recent tests made at the North Side Works on dry plates showed that the flow through the plate was proportional to the pressure drop; the flow is therefore of straight-line or viscous type.

The viscosity of a gas varies with the temperature, but is independent of the pressure (Walker, Lewis & McAdams, *Principles of*

Chemical Engineering, page 78). Since the viscosity of air is the same at a barometric pressure of 29 inches of mercury as at 30 inches, a diffuser plate rated at the two pressures will have the same permeability if the temperature of the air is the same and the permeability is expressed in cu. ft. per min. at the barometric pressure at which the test is made. Calculating to a standard barometric pressure introduces an error.

Orifice-type flow meters calibrated with a displacement meter are used to make the permeability test. An orifice-type flow meter that has been calibrated to read in permeability at a barometric pressure of 30 inches of mercury will not indicate the correct permeability when used at another barometric pressure, say 29 inches of mercury. The following calculations for the two conditions show the magnitude of the error.

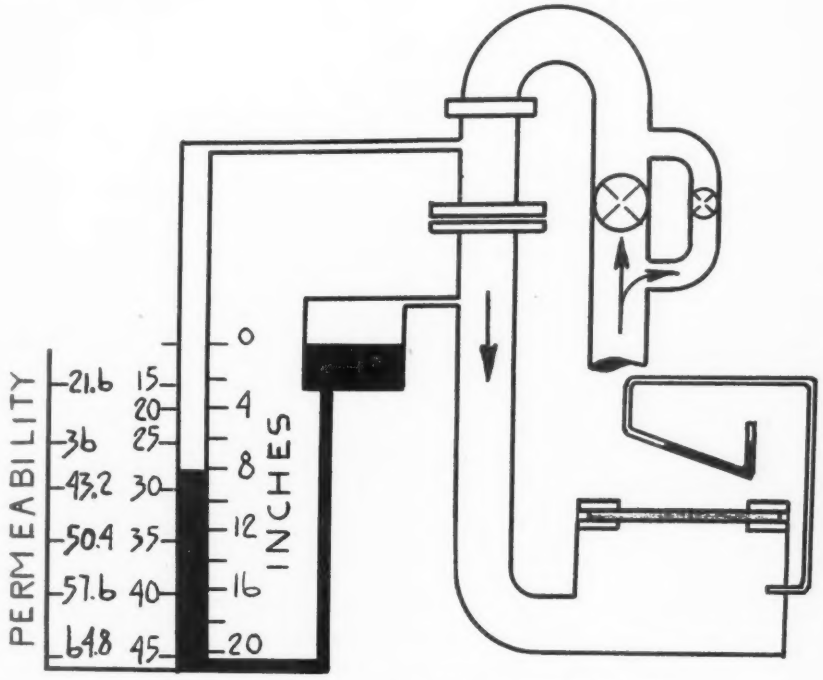

FIG. 8.—Orifice meter used in making permeability tests.

Figure 8 shows a typical orifice-type meter such as is used in making permeability tests. The test air is expanded ahead of the orifice, which is of the thin plate type, ¾ inches in diameter, in a 6-inch pipe. A calibration curve for this orifice was at hand and was used to calculate the discharge coefficient used in the calculations.

Calculation

Density of air at 32° F.	29.9 inches of mercury	.0807
Density of air at 70° F.	30 inches of mercury	.0748
Density of air at 70° F.	29 inches of mercury	.0723

$W = C\sqrt{2gh}$ (Walker, Lewis and McAdams, *Principles of Chemical Engineering*)

Where

W = Average linear velocity
C = Coefficient of discharge (.77)
g = 32.2 ft. per sec.
h = Fluid head, expressed in feet of fluid flowing

At 30 inches of mercury barometric pressure, 8 inches of water differential pressure and a pressure of 2 inches of water under the plate. Down stream pressure absolute:

$$30 + \frac{2.0}{13.6} = 30.15 \text{ inches of mercury (sp. gr. = 13.6)}$$

$$\frac{30.15}{30.00} \times .0748 = .0752 \text{ density of air at flowing conditions}$$

$$\frac{8}{12} \times \frac{62.3}{.0752} = 552 \text{ head in feet of gas } (h)$$

$$W = .77\sqrt{2 \times 32.2 \times 552} = 145.2 \text{ feet per sec. (velocity)}$$

$$145\,2 \times \frac{.75^2 \times .785}{144} \times 60 = 26.7 \text{ cu. ft. per min. at 30.15 in. of mercury}$$

$$\frac{30.15}{30.00} \times 26.7 = 26.85 \text{ cu. ft. per min. at 30 in. of mercury}$$

$$26.85 \times \frac{144}{100} = \textit{38.8 permeability.}$$

At 29 inches

$$29 + \frac{2.0}{13.6} = 29.15 \text{ inches of mercury}$$

$$\frac{29.15}{30.00} \times .0748 = .0727 \text{ density of air at 70° F. and 29.14 bar. pressure at flowing conditions}$$

$$\frac{8}{12} \times \frac{62.3}{.0727} = 571 \text{ head in feet of gas } (h)$$

$$.77\sqrt{2 \times 32.2 \times 571} = 147.7 \text{ feet per sec. (velocity)}$$

$$147.7 \times \frac{.75^2 \times .785}{144} \times 60 = 27.3 \text{ c.f.m. at 29.15 inches of mercury}$$

$$\frac{29.15}{29.00} \times 27.3 = 27.45 \text{ c.f.m. at 29 inches of mercury}$$

$$27.45 \times \frac{144}{100} = \textit{39.55 permeability.}$$

From the calculations just given it may be concluded that if a permeability test apparatus, calibrated in permeability at a barometric pressure of 30 inches of mercury, is used at a barometric pressure of 29 inches of mercury, a plate found to have an apparent rating of 38.8 would actually rate 39.55 if rated at 30 inches barometric pressure, or there would be a difference in permeability of .75 c.f.m.

This difficulty may be avoided if master plates are selected in the testing range at the barometric pressure prevailing at the time of calibration. The master plates may then be used to check the apparatus from time to time. This practice is being followed by the diffuser plate manufacturers.

An examination of the report on the permeability tests on 9000 diffuser plates for the Calumet Works Extension showed that three master plates were used to check the test apparatus four times daily. The testing covered a period of 22 days with a maximum variation in barometric pressure from 29.01 to 30.08 inches of mercury. The maximum variation in permeability was + .30 cu. ft. per min., which occurred on one occasion.

From these results it may be concluded that the barometric pressure is not an important factor in the permeability test and that the permeability test equipment used was not sufficiently sensitive to record the effect of a change in barometric pressure of one inch of mercury.

TABLE V.—*Effect of Temperature of Plate on Permeability*

Plate No.	Manufacturer	Temperature in Degrees Fahrenheit	Permeability
1	A	70.0 44.6	41.4 43.6
2	A	70.0 42.8	41.4 43.9
3	A	70.0 84.2	41.5 39.8
4	A	70.0 86.0	41.5 39.8
5	B	70.0 25.0	38.0 41.5
6	B	70.0 53.0	39.5 40.0
7	B	70.0 53.0	39.7 40.6
8	B	70.0 53.0	39.9 41.7
9	B	70.0 26.0	30.1 33.1
10	B	70.0 26.0	30.1 33.1
11	B	70.0 26.0	30.1 33.0

Effect of Plate Temperature on Permeability

At the time the permeability tests were made on the plates purchased for the Calumet Extension, a series of tests were made to determine the effect of temperature of plates on the permeability rating.

A number of plates were rated at 70° Fahrenheit. Some of these plates were then cooled and others were warmed, the temperature taken and the permeability test made at the new temperatures. The results are presented in Table V. The change in permeability with the change in temperature of the plate can be accounted for by the change in volume and viscosity of the air, due to the change in temperature of the air on coming in contact with the plates. The results show that it is necessary to rate plates at a uniform temperature.

Effect of Humidity of Room Air

Three diffuser plates were rated after being stored in a room with the air temperature at 70° Fahrenheit and the relative humidity 71 per cent. Later the plates were again rated with the air at the same temperature and 42 per cent relative humidity. No change in permeability was observed.

Effect of Humidity of Test Air

To determine the effect of relative humidity of the test air, a plate was rated a number of times with relative humidity of the test air varying from 71 to 27 per cent. Permeability readings varying from 41.2 to 41.6 were obtained. A variation of this magnitude in the permeability test may be expected from other causes. It may therefore be concluded that the relative humidity of the test air up to 71 per cent causes no detectable change in the permeability test.

From theoretical considerations, little effect on the permeability test would be expected by a change in the relative humidity of the test air. At 70° Fahrenheit and 71 per cent relative humidity, air contains only 1.1 per cent of water vapor by volume. Water vapor at that temperature has a viscosity of .0105 centipoise while dry air has a viscosity of .0180 centipoise. The addition of sufficient water vapor to obtain a relative humidity of 71 per cent reduces the viscosity of the mixture to .0179 centipoise, or a reduction of only 0.6 per cent.

Conclusions

1. Diffuser plates that have been subjected to an accurate permeability test will give uniform distribution when placed in an aeration tank.

2. Diffuser plates with permeability ratings as high as 67 will give uniform distribution.

3. There is a slight increase in bubble size with plates of higher permeability. There is also a slight increase in bubble size with an increase in air rate.

4. The increase of pressure loss through diffuser plates with use varies inversely with the permeability.

5. A change in barometric pressure affects the permeability test. The effect, however, is not great enough to be detected by ordinary permeability test apparatus.

6. The temperature of a diffuser plate is the most important factor affecting the permeability test.

7. A change in the relative humidity of test air or room air has no detectable effect on the permeability of a plate, when the humidity is maintained under 71 per cent.

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USE OF "CLOROBEN" IN SEWAGE TREATMENT*

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A series of laboratory experiments were conducted to determine the possible uses of "Cloroben" in sewage treatment and sewage disposal. "Cloroben" is a trade name for a liquid which consists principally of ortho-dichlorbenzene.

The preliminary studies were conducted to determine whether comparatively small quantities of Cloroben affected the rate of aerobic decomposition in respect to suspended solids, oxygen consumed, B.O.D., nitrification and general respiration, settleability of solids, concentration of sludge and to determine the effect of larger quantities of Cloroben on the retardation or inhibition of the bacterial activities in sludge, including sludge digestion.

The preliminary laboratory experiments were followed by a limited number of field tests at three sewage treatment plants, but the results obtained are not included in this paper. Since the purpose of the experiments was to determine the possible uses of the material, the experiments were not exhaustive, but only sufficient to show the merits and demerits of the solvent.

Effect of Cloroben on Bacteria

Some results dealing with the effect of the material upon total bacteria (20° count) and the resultant odor of the mixtures are shown in Table I. Raw sewage from Freehold, N. J., was treated with large

Table I.—*Effect of Cloroben on Bacteria and Odor*

Cloroben, p.p.m.	0	5.3	106	212	662	1,325	2,650	6,625	13,250	26,500
Bacteria, per cent Remaining	4,400*	73†	52†	93	0.5	0.05	0.025	0.016	0.022	0.01
Odor (2 days)	H_2S	H_2S	H_2S+C	C+H_2S	C	C	C	C	C	C

* Thousands per c.c.; C = Cloroben.
† 2 days contact.

amounts of Cloroben and after treatment samples were allowed to stand for two days, after which the odor of the mixture was estimated. It is apparent that extremely large quantities of Cloroben were necessary to effect a material reduction in total bacteria. Even with 106 p.p.m. Cloroben and two days contact, the bacterial reduction amounted to only 50 per cent. The low percentage reduction may be due in part to the aftergrowth of the organisms, similar to that observed for chlorinated materials. Hydrogen sulphide was not inhibited with small

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Div. Water and Sewage Research.

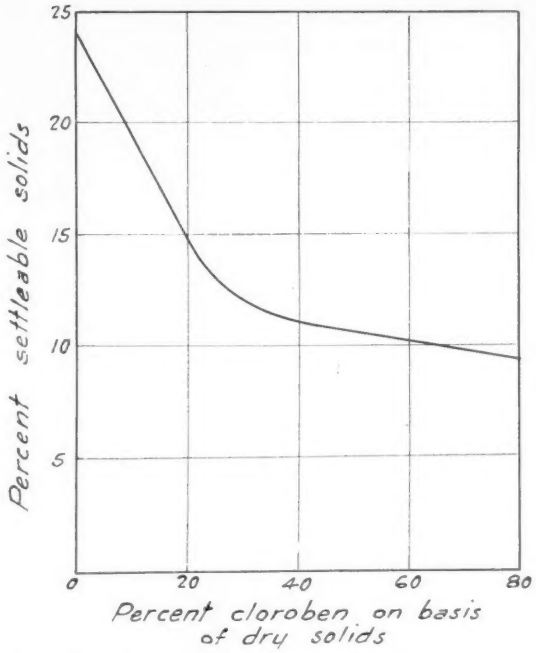

FIG. 1.—Effect of Cloroben on compacting of stale sewage solids.

quantities of Cloroben and could not be detected with larger amounts on account of the masking effect of the solvent odor.

EFFECT ON SETTLING AND COMPACTING OF SOLDIDS

Stale sewage solids have a tendency to become bulky after settling. In an effort to determine the effect of Cloroben upon the compacting of such solids previously settled, different quantities of the solvent were added. With increasing quantities, the mass compacted rapidly as indicated in Figure 1, illustrating the compacting effect on stale sewage solids (2 per cent) in one hour. With 0.4 per cent Cloroben on a wet basis (20 per cent, dry basis) the material compacted 50 per cent in that time.

Cloroben had little effect on the compacting of activated sludge over a period of several days. The activated sludge had a concentration of 1 per cent solids and Cloroben was added in varying amounts from 0 to 2 c.c. per 100 c.c. of sludge, or on the basis of dry solids from 0 to 265 per cent. An example with additions of a somewhat reasonable quantity of Cloroben shows the following:

Cloroben, per cent	0	2.65
Hours Settled	Sludge Settled by Volume, per cent	
6	98	98
12	74	70
72	60	57
120	51	50
162	51	49

In an effort to determine the effect on the rate of settling of activated sludge, a series of experiments were conducted with increasing quantities of Cloroben. Activated sludge mixtures containing approximately 2,000 p.p.m. suspended solids were treated with quantities of the solvent varying from 0 to 500 parts per million. During the first 30 minutes the rate of settling increased with the quantity of Cloroben added. The difference between the tests and the control decreased materially after 60 minutes and there was practically no difference after two hours. The activated sludges used were in "good conditions" having a sludge index (per cent volume divided by per cent suspended solids) of 15 in 30 minutes. It was interesting that even such rapidly settling sludge was affected by the material added. Ordinarily there would be no point in treating such rapidly settling activated sludge. An insufficient number of experiments with "poor" or "bulky" activated sludge does not allow the drawing of definite conclusions.

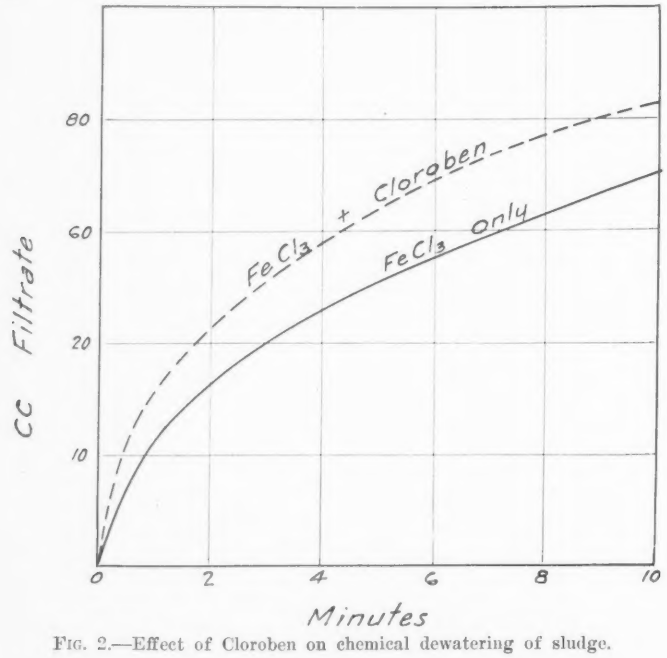

FIG. 2.—Effect of Cloroben on chemical dewatering of sludge.

EFFECT ON DEWATERING OF FRESH SOLIDS

Dewatering experiments with Cloroben were conducted to find if the solvent would aid in the removal of more water from the cake when added in approximately optimum quantities prior to iron salts.

When small quantities of Cloroben were added to fresh solids of 7 per cent concentration, followed by stirring and addition of ferric chloride, and filtration after 5 minutes under a vacuum of 21 inches, there was no effect. With increased quantities of Cloroben more water

drained off in the same filtration time than when no Cloroben was added. Results of a typical experiment, using 120 grams sludge (7 per cent solids) to which a large quantity of Cloroben (1.32 grams) was added after treatment with $FeCl_3$, are shown in Figure 2 in comparison with the same sludge receiving $FeCl_3$ only. After 10 minutes filtering the difference in filtrate amounted to 15 per cent. The weight of the wet cake was, for $FeCl_3$ only, 50.79 grams and for $FeCl_3$ plus Cloroben, 42.07 grams. The cake with the Cloroben had a strong odor of the solvent. "Split treatment," in which half of the iron salt was added immediately after the solvent was mixed with the sludge and the other half after 10 minutes, was less effective than adding all the iron salt in one dose immediately after the Cloroben was added.

Effect on Coagulation of Sewage

The turbidity and settlability of suspended solids of sewage were unaffected by the addition of Cloroben up to 100 p.p.m., followed by a 4-hour contact period. With larger quantities the turbidity increased due to colloidal dispersion of the Cloroben, while the volume of settleable solids increased, as the solvent separated and sank to the bottom.

Effect of Dispersion of Cloroben

Cloroben added to sewage has a tendency to form globules which settle comparatively rapidly. Dispersion of the material is necessary because reaction between the water-insoluble Cloroben and sewage particles is accomplished by surface action. From a practical standpoint this means proper dispersion by mechanical means or facilities for thorough mixing of the material with the sewage. Shaking of sewage-Cloroben mixtures was successful with small quantities of the latter, but with larger amounts such a method of dispersion did not prevent separation and settling. To determine the effect of dispersion of large quantities, alcoholic solutions of Cloroben were used. This means of obtaining proper dispersion is obviously impossible in practice, both from the standpoint of cost and the inadvisability of adding large quantities of alcohol, and organic substance unstable in sewage. Since the results were rather significant, they were briefly summarized.

A 10 per cent solution of Cloroben in 95 per cent alcohol was added to 2.5 liter samples of sewage, in quantities varying from 0 to 520 p.p.m. Cloroben. All samples were thoroughly shaken and analyzed after 4 hours contact. The samples were then stored in open bottles for a period of 30 days and observations made at intervals. Some of the results are given in condensed form in Table II. The B.O.D. of the sewage before treatment was about 300 p.p.m., but due to the alcohol addition, it increased to over 400 p.p.m. No effect was noticed on the suspended solids or ammonia. Bacterial results were very similar to those obtained with undissolved Cloroben and only with large quantities of the material was the normal bacterial population affected. The odor of the sewage was changed by the addition of the smallest quantity

TABLE II.—*Condensed Results on Effect of Distribution of Cloroben*

Cloroben Added, p.p.m.	0	10.4	104	520
Alcohol Added, p.p.m.	2000	2000	2000	4000
Suspended solids, p.p.m.	280	280	280	280
NH_3–N, p.p.m.	60	60	60	60
B.O.D. (5-day), p.p.m.	>400	>400	>400	>400
Total Bacteria 20° C.—48 hrs., thous./c.c.	3000	2500	700	1.5
Total Gas Formers, thous./c.c.	100	100	50	1
B. Coli, thous./c.c.	100	100	55	10
Odor * 4 hrs.	S	fs + fc	st c	vst c
5 days	as	fs	fs + fc	st c
30 days	as	fs	fs	st c
pH 4 hrs.	6.8	6.8	6.8	6.8
30 days	4.5	8.2	8.3	7.6

* S = Sewage, C = Cloroben, f = faint, st = strong, vst = very strong, a = acid or sour.

of Cloroben, and when the Cloroben odor disappeared (5 days in the case of 10 p.p.m. Cloroben) the odor of the remaining sewage was far less intense than the control and somewhat less than the original odor. In spite of the fact that, after 4 hours contact, bacterial numbers of the Cloroben treated sewages were not reduced with small quantities, the pH values remained constant or gradually increased, whereas the untreated sewage registered a gradual decrease in pH values, so that the intensity of the sour odor became more and more pronounced. Little or no coagulation or floc formation occurred in the control, while the suspended solids in treated samples appeared to be curdled. It appeared that organisms responsible for acid decomposition were affected by the treatment to the extent that no accumulation of organic acids occurred. Decomposition proceeded at a slow rate, while a certain amount of clarification and coagulation took place without emanation of foul odors, producing a rather clear effluent. With the largest quantities of Cloroben, anaerobic digestion was practically prevented.

EFFECT OF DISTRIBUTION OF CLOROBEN

Trial experiments indicated that in order to obtain the most beneficial effect the Cloroben should be well distributed throughout the liquid. Various methods were tried. To liter samples of sewage, Cloroben was added and mixed gently, rapidly, violently for 5 minutes, air passed rapidly through the liquid from 5 to 30 minutes and the results compared with those in mixtures receiving 10 per cent Cloroben in alcohol, and with sewage receiving no treatment.

The results indicated that addition of Cloroben to sewage without proper mixing was unsatisfactory. Best results were obtained with aeration, and/or rapid mixing of a 10 per cent solution in alcohol. Regardless of treatment there was no immediate tendency toward floc formation. With insufficient mixing it was observed that very fine droplets coalesced and settled, thus increasing the volume of settleable solids. Dispersion with an atomizer submerged into the liquid resulted in a Cloroben colloid that was dispersed sufficiently to remain stable for more than 30 minutes.

Effect on Aerobic Decomposition of Sewage

Experiments were undertaken to determine whether small quantities of Cloroben would affect the rate of aerobic decomposition in sewage oxidation devices and streams, in respect to suspended solids, oxygen consumed, B.O.D., nitrification and general respiration; and to determine the effect of larger quantities of Cloroben on the retardation or inhibition of biological activities.

Procedure.—One-liter samples of sewage were placed in aeration tubes and Cloroben was added in quantities equivalent to 0, 13, 200 and 500 parts per million. Carbon dioxide-free air was passed into the bottom of the tubes in very fine bubbles, which insured intimate contact of the reagent with the sewage particles. The air was collected at the top of the aeration tubes and washed to recover any carbon dioxide evolved during the aerobic digestion of the sewage. Aeration was continued for a period of 20 days and the CO_2 was determined daily, or whenever it was deemed necessary. Concordantly other determinations such as the nitrogens, suspended solids, B.O.D. and oxygen consumed values were made at intervals.

Results.—The composite results have been condensed and are given in Table III. Summarizing the results it appears that:

1. The reduction of suspended solids after 20 days was practically the same with or without treatment with Cloroben. The maximum

Table III.—*Condensed Results, Sewage Aeration (Aerobic Digestion)*

Analyses	Dig. Per. Days	Cloroben, p.p.m.			
		0	13	200	500
Suspended Sol. p.p.m.	0	365	365	365	365
	20	162	167	153	181
Reduction, per cent	20	55.6	54.2	58.0	50.4
Oxygen Cons., p.p.m.	0	495	495	510	495
	5	228	247	268	307
	20	170	176	166	160
Reduction, per cent	5	54.0	50.0	52.2	38.0
	20	65.7	64.4	64.0	67.6
B.O.D., p.p.m.	5	342	324	332	285
	15	502	469	447	425
Reduction, per cent	5	—	5.3	3.0	16.7
	15	—	6.6	10.9	15.3
CO_2 Production, p.p.m.	1	130	126	119	19
	5	538	547	616	522
	15	927	897	950	901
NH_3–N, p.p.m.	0	37.0	37.0	37.0	37.0
	5	0.25	0.25	0.25	20.0
	20	tr.	tr.	tr.	tr.
NO_2–N, p.p.m.	0	tr.	tr.	tr.	tr.
	5	6.8	7.0	7.5	0.15
	20	0.01	0.04	3 0	12.0
NO_3–N, p.p.m.	0	tr.	tr.	tr.	tr.
	5	4.0	5.44	8.6	0.42
	20	1.3	2.15	3.8	9.92

Cloroben treatment showed 5 per cent less reduction of solids than in the control, which is within the experimental error.

2. After five days the oxygen consumed value was considerably higher (25.8 per cent) with the largest amount of Cloroben. This indicates that the Cloroben had a retarding affect on the aerobic organisms, which effect disappeared on prolonged digestion. Quantities of Cloroben up to 200 p.p.m. had no apparent effect on oxygen consumed values.

3. The B.O.D. figures indicate a slight retarding effect by increasing quantities of Cloroben. The effect appeared even after 15 days, although the maximum reduction (500 p.p.m. Cloroben after 5 days) was less than 17 per cent.

4. During the first day of aeration there was a slight retardation of respiration with treatments of 13 and 200 p.p.m. Cloroben, while 500 p.p.m. nearly inhibited digestion. With continuous aeration the effect became less, so that after five days the inhibiting action had been overcome. The gradual change or loss of inhibitory effect may have been due to loss of Cloroben by aeration.

5. Most of the ammonium compounds (93 per cent) disappeared after the fifth day in all mixtures, except that of sewage and the largest quantity of solvent, where the reduction amounted to only 46 per cent. After twenty days only a trace of ammonia remained in all mixtures.

6. Nitrite formation was very active in the mixtures, except that receiving the largest quantity of Cloroben. Nitrite formation was even more active after five days in the mixtures with smaller quantities of solvent than in the control. Gradually the mixture receiving 500 p.p.m. Cloroben became more and more active until after twenty days, when most of the nitrites had disappeared in the other mixtures, comparatively large quantities were present.

TABLE IV.—*Carbon Dioxide Production of Mixtures in Mgrms. per Liter Sewage*

Period, Hr., from-to	Time Interval, Hr.	Cloroben, p.p.m.			
		0	13	200	500
0– 19	19	130.0	126.5	119.0	19.0
19– 48	29	150.7	155.1	176.0	171.0
48– 65	17	95.7	76.5	81.4	80.3
65– 97	32	111.1	138.6	129.8	173.8
97–120	23	50.6	50.6	110.0	77.0
120–148	24	51.7	63.8	57.2	47.3
148–244	96	152.5	159.5	161.1	161.5
244–388	144	184.6	126.5	115.5	170.5
388–480	92	69.8	—	83.1	66.5

7. Nitrate formation progressed more rapidly with the smaller quantities of Cloroben than in the control. With the larger amount of solvent, nitrate formation was first retarded and later stimulated. Eventually the quantities of nitrate nitrogen became less, probably due to partial re-synthesis as microbial nitrogen, while a portion of the ni-

trogen present as ammonium compounds, unstable organic nitrogen and nitrite nitrogen was volatilized as ammonia (very small quantities) and as nitrogen gas through the nitrite-amino-diazo reaction.

Respiration.—The progress of aerobic digestion is indicated by the carbon dioxide production of sewage to which different quantities of Cloroben were added.

Results for different periods are given in Table IV, while the cumu-

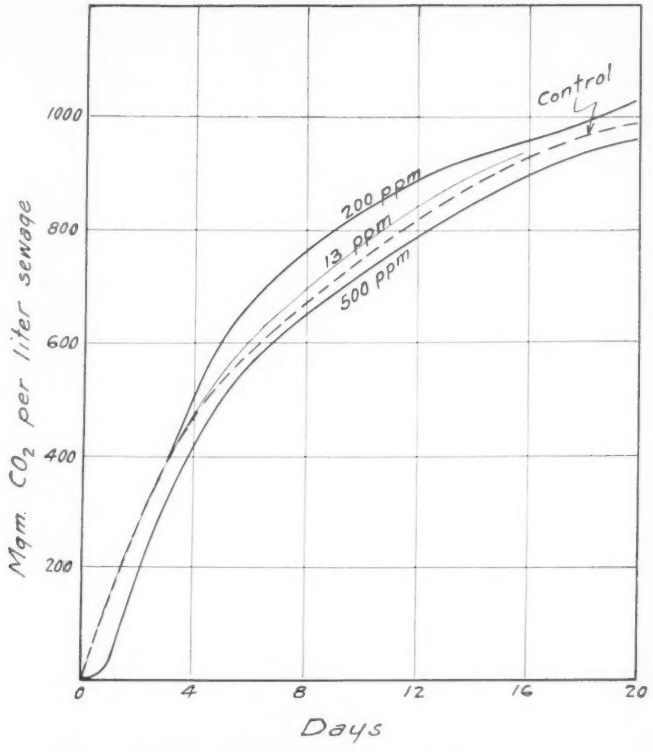

FIG. 3.—Effect of Cloroben on CO_2 production of sewage.

lative results are graphically illustrated in Figure 3. From the cumulative results it would appear that additions of Cloroben up to 200 p.p.m. had a slight stimulating effect, while with larger quantities a slight retarding effect was exhibited. Close inspection of the curves shows that only one day was required under these conditions before the aerobic organisms had adjusted themselves to their new environment in samples containing up to 500 p.p.m. Cloroben. In order to determine more clearly whether the effect of the Cloroben was continuous or cumulative, the average velocity of carbon dioxide production at successive stages of aerobic decomposition was calculated, and the results expressed in milligrams of CO_2 evolved per hour (Table V). It is evident that the rates of CO_2 production of the samples which had

TABLE V.—*Average Velocity of CO_2 Production at Successive Stages of Aerobic Decomposition of Sewage (Mgrms. CO_2 Evolved per Hour)*

Period		Cloroben, p.p.m.			
Hrs.*	Hrs.†	0	13	200	500
19	9.5	6.83	6.65	6.25	1.00
29	23.5	5.18	5.33	6.05	5.90
17	56.5	5.63	4.50	4.78	4.72
32	81.0	3.47	4.32	4.05	5.42
23	108.5	2.20	2.20	4.78	3.34
24	132.0	2.15	2.66	2.38	1.97
96	196.0	1.59	1.66	1.68	1.68
144	316.0	1.28	0.88	0.83	1.22
92	434.0	0.76	—	0.94	0.72

* The period over which a mean rate of CO_2 production was calculated.
† The hour at which a given mean rate most likely coincided with the actual rate.

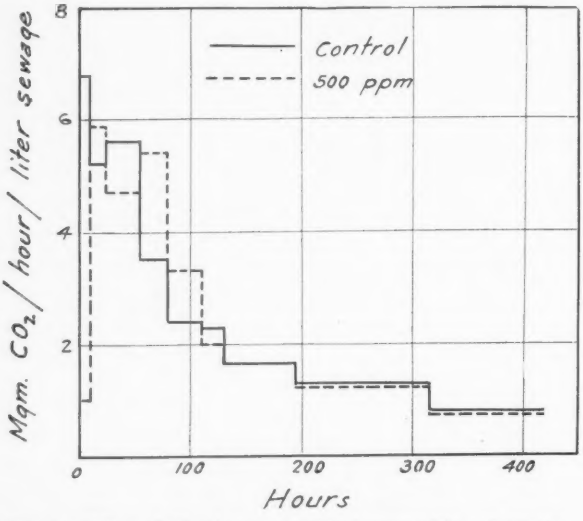

FIG. 4.—Effect of Cloroben on aerobic decomposition of sewage.

received 13 and 200 p.p.m. Cloroben were slightly lagging during the first 10 hours, and somewhat faster thereafter, reaching a low rate sooner than the control. The final quantity of CO_2 produced per liter of sewage in a given time was in all instances approximately the same. The stimulating and retarding effects on biological activity were especially noticeable during the first 24 hours but had completely disappeared by the fourth day of digestion. This action is more clearly illustrated in Figure 4, where the rates of CO_2 production of the control are compared with those of the sample receiving 500 p.p.m. Cloroben.

EFFECT OF ACTIVATED SLUDGE

In prior experiments it was indicated that small quantities of Cloroben gave a slightly more rapid rate of aerobic decomposition of sew-

age solids and that large quantities retarded aerobic decomposition. In another experiment small quantities of Cloroben retarded anaerobic decomposition. These two indications suggested the possibility of (*a*) stimulating the aerobic biological activity of the activated sludge process, and (*b*) prevention of deterioration of activated sludge during periods when air can not be supplied, such as during settling and compacting.

Stimulation

Procedure.—To equal portions of fresh sewage and activated sludge, aerated in bottles, 0, 5, and 10 p.p.m. Cloroben were added at successive stages. The sewage was rather strong, containing approximately 500 p.p.m. suspended solids, while the resultant mixtures of sewage and activated sludge in the aeration chambers contained from 1,300 to 1,400 p.p.m. suspended solids. The mixtures were aerated for 4, 5, and 6 hours prior to the determination of sludge settlability, oxygen consumed and turbidity of the effluent. The supernatant liquid was drawn off, additional treated sewage added and the process repeated a number of times. The loading of the original activated sludge was purposely made excessive so that any differences in the capacities with and without Cloroben treatment would be more pronounced. The aeration time was varied from 2.5 to 21.5 hours.

Results.—The differences between the treated and untreated samples in the individual tests was very small. Typical average results were as follows:

Cloroben Added, p.p.m.	0	5	10
Settling, 30 min., per cent	20.8	20.5	20.6
Oxygen Cons., p.p.m.	93	100	99
Turbidity	51	49	46

Any differences which occurred were well within the experimental error. It is always of interest to note how much punishment activated sludge can stand, as indicated again by these experiments.

Retardation

Cloroben was added to activated sludge for the purpose of retarding anaerobic organisms during "rest periods" and thus preserve its vitality.

Procedure.—Returned activated sludge, collected from a New Jersey plant, was treated as follows: (*a*) aerated five days without sewage, (*b*) stored in closed bottles for five days, (*c, d* and *e*) treated with 100, 200 and 500 p.p.m. Cloroben respectively and stored for five days. Each mixture contained 9,300 p.p.m. suspended solids. After five days, seven volumes of fresh sewage were mixed with one volume of each of the treated sludges, and the mixtures were aerated until fairly satisfactory clarification and purification resulted. After one hour quiescent settling the supernatant liquid was decanted and fresh sewage

TABLE VI.—*Effect of Cloroben on Recovery of Activated Sludge*

Sludge Treatment	Analyses	Aerated 5 Days	Stored 5 Days	Stored 5 Days with Cloroben		
				100 p.p.m.	200 p.p.m.	500 p.p.m.
Sludge before sewage addition	Floc	Dense, gran.	Fine	Granular	Granular	Granular
	Color	Brown	Blackish brown	Golden brown	Golden brown	Golden brown
	Odor	Bitter	Foul	Distinct cloroben	Strong cloroben	Very strong cloroben
7 sew. 1 sludge, aerated 8 hr.	Per cent settling, 1/2 hr.	17.4	17.6	17.5	17.6	17.5
	Turbidity, p.p.m.	14	38	14	14	14
	O_2 cons., p.p.m.	31.8	29.9	27.6	33.2	41.2
Liquid replaced by sewage, aer. 10 hr.*	Per cent settling, 1/2 hr.	19.6	17.1	17.7	19.0	17.1
	Turbidity, p.p.m.	15	25	15	20	50
	O_2 cons., p.p.m.	29.5	36.5	31.8	32.3	47.2
	Color	Brown	Black-brown	Brown	Brown	Brown
Susp. solids replaced by sew. aer. 11 hr.	Turbidity, p.p.m.	12	18	12	12	13
	O_2 cons., p.p.m.	26	25.5	20	26	32
	Color	Brown	Brown	Brown	Brown	Brown
Aeration discont. 16 hr.	Color	Black	Black	Black-brown	Brown	Brown
Liquid replaced by sewage, aer. 7 hr.	Per cent settling, 1/2 hr.	21.4	20.7	20	18.6	16.4
	Turbidity, p.p.m.	40	40	40	40	40
	O_2 cons., p.p.m.	41	40	34	39	45
	Color	Brown	Brown	Brown	Brown	Brown

* Cloroben odor disappeared after this treatment.

was added to the remaining sludge. After three such treatments, aeration was discontinued for sixteen hours and then fresh sewage was added, followed by aeration for seven hours. The suspended solids content of the sewage was about 150 p.p.m. and of each mixture approximately 1,300 parts per million.

The drastic treatment given all sludges prior to aeration obviously would occur rarely in practice, but if Cloroben prevented the deterioration of the adsorptive properties of the sludges to which it had been added, as well as preserved favorable environmental conditions for aerobic biological growth once oxygen was admitted, a more rapid rate of recovery could be expected than would be found for septic sludge. Furthermore, if Cloroben had a stimulating effect on aerobic biological activities, better results would be expected over the sludge kept in condition by continuous aeration, but without the addition of fresh sewage.

Results.—The results of a series are shown in Table VI. It is evident that the results indicate relatively insignificant differences in respect to purification. With increasing quantities of Cloroben the sludge density increased, but the sludge treated with the highest quantities of Cloroben gave comparatively inferior purification. From the standpoint of appearance, the golden brown color usually associated with a "good" quality of activated sludge was preserved in the sludges containing Cloroben and was destroyed upon resting the sludge without Cloroben.

The quality of all effluents was very similar, except that which received the largest amount of Cloroben. As an example, the average oxygen consumed values for four runs were as follows:

Cloroben, p.p.m.	0	0	100	200	500
Oxygen consumed	32.1	33	28.3	32.6	41.3

These results lead to the conclusions that 500 p.p.m. Cloroben treatment of activated sludge was somewhat detrimental, under the conditions of these experiments. If it be assumed that the Cloroben was retained by the sludge, the largest quantity approximately added was 5 per cent on the dry solids basis, and if dispersed into the clarified sewage, the equivalents would be 62 p.p.m. for the first passage and 3 p.p.m. for the last. The disappearance of the odor would be of interest if Cloroben were added to sewage and the treated effluent was passed into streams used for potable water supplies.

Effect on Storage of Activated Sludge

The purpose of the experiment was to determine the effect of Cloroben on activated sludge stored for long periods. Storage of the activated sludge may be desirable before disposal of the material into the sea or other bodies of water, or when placed in lagoons, in order to prevent nuisances such as odors or fly breeding.

Procedure.—Returned activated sludge containing about 9,300 p.p.m. suspended solids, having the typical golden brown color, was treated with 100, 200 and 500 p.p.m. Cloroben, on a volume basis, and stored in closed bottles for a total length of more than twenty days. Notes were taken at frequent intervals. At the start a slight solvent odor was present in the sample with 100 p.p.m. Cloroben, distinct with 200 p.p.m. and strong with 500 p.p.m. Notes taken after five and again after twenty days are condensed and shown in Table VII.

It is evident that the rate of anaerobic decomposition of activated sludge was retarded by Cloroben treatment of 1 to 2 per cent on the dry solids basis. This retardation was very pronounced with the addition of 5 per cent Cloroben, resulting in very little biological activity.

TABLE VII.—*Effect of Cloroben on Storage of Activated Sludge*

Cloroben, p.p.m.	0	100	200	500
After 5 days				
Color	Black	Golden brown	Golden brown	Golden brown
Odor	Foul	Slight C	Distinct C	Strong C
Gas	Few bubbles	Few in sludge	Few	None
Supernatant	Turbid	Clear	Clear	Clear
Settling, 1/2 hr.*	20	20	19	17
After 20 days				
Color	Black	Brown	Brown	Light brown
Odor	Foul	Slight C	Distinct C	Distinct C
Gas	Freely gasif.	Consid.	Some	Very little
Supernatant	Very turbid	Slightly turbid	Faint turbid	Clear
Sludge	Thin, dispersed	On top, curdled	Curdled	Curd dispersed
Settling, 1/2 hr.*	80	50	25	10

* Settling after shaking, per cent by volume.

The curdling effect and subsequent condensing of the activated sludge after storage for twenty days is of interest in respect to discharge of sludge in large water bodies and possibly in connecting with certain types of lagooning.

Effect on Storage of Sewage

To determine the effect of Cloroben on prolonged storage of sewage, two-liter samples were treated with 0, 13, 50, 200 and 500 p.p.m. Cloroben and stored in acid bottles fitted with Bunsen valves. Notes were taken at intervals for a period of thirty days. The results show that storage with 13 p.p.m. Cloroben prevented the production of odors for a period of twenty-five days, while addition of 200 p.p.m. or more appeared to produce sterilization, which was maintained for thirty days, when the experiment was terminated. The color of the sludge remained gray with all treatments; the supernatant remained clear with treatment up to 50 p.p.m. and eventually became turbid with the higher treatments.

Effect on Storage of Raw Sludge

For the determination of the effect of Cloroben upon the decomposition of fresh sewage solids, batches containing approximately 5 per

cent total solids were treated with 500 p.p.m. Cloroben, or 1 per cent on the dry solids basis. The solids were placed in bottles and the CO_2 evolved by anaerobic decomposition was absorbed in alkali. Storage during the earlier days is of greatest interest, because no attempt was made to sterilize the material completely. Results after three and six days of storage were as follows, expressed in milligrams CO_2 evolved per 100 grams dry raw sludge:

Days Storage	3	6	(6 less 3)
Control	123.2	475.2	352
Cloroben, 1 per cent	79.2	435.2	356

The Cloroben-treated sludge formed a rather firm gel at the surface. Approximately 60 per cent was scum and the remainder light gray supernatant, while the control scum occupied the same volume, but was easily broken up by shaking. The supernatant had a yellowish gray color. The decomposition of the gray solids was retarded during the first three days but not thereafter. The odor of the treated sample was masked by the Cloroben, but after the sixth day the combination odor of stale solids and Cloroben was distinctly disagreeable and possibly not less vile than that of the stale sewage solids. It appears, therefore, that one per cent of Cloroben, on the dry solids basis, retarded decomposition for a few days but was not effective in decreasing or masking completely the odor of stale sewage solids after six days, nor preventing septicity of fresh solids for more than three days.

Effect on Sludge Digestion

In order to determine the effect of comparatively large quantities of Cloroben on the digestion of properly seeded fresh solids, from the standpoint of the rate of decomposition, fresh solids were seeded with ripe sludge on a 1:2 basis and allowed to undergo anaerobic decomposition at 28° C. The first stage of digestion is of greatest interest; the course of digestion is indicated by the amount of CO_2 given off per 100 grams total solids in Table VIII for the first three and one-half and seven days of digestion.

Table VIII.—*Effect of Cloroben on CO_2 Production of Digesting Mixtures*

Cloroben, Per Cent on Dry Solids Basis	Milligrams CO_2 per 100 Grams Dry Solids		
	3½ Days	7 Days	3½ to 7th Day
0	1245	2750	1505
0.2	712	2005	1293
0.4	652	1835	1183
1	603	1855	1252
2	590	1875	1285
3	408	1215	807

Results.—A marked retardation of digestion occurred during the first three to four days of digestion with 0.2 per cent Cloroben, on the dry basis, or approximately 100 p.p.m. Only about half as much CO_2 gas was evolved when the treatment varied between 0.2 and 2 per cent Cloroben. When 3 per cent Cloroben was added a further reduction, amounting in total to 66 per cent, occurred. After three days most of the retarding effect was lost, with treatment under 3 per cent, while the highest treatment still showed a 56 per cent reduction over the control.

On the sixth day the samples were thoroughly shaken and the distribution of the solids observed the following day. With the exception of the highest Cloroben treatment, in which 80 per cent of the solids were at the bottom and the remainder as supernatant, all samples showed approximately the same solids distribution, namely 50 per cent sludge, 25 per cent scum and 25 per cent supernatant.

The retarding effect on anaerobic decomposition of these relatively large amounts of Cloroben, which in effect "weigh down" the solids, was shown by the absence of rapidly forming gas bubbles in the sludge. This allowed more compacting of the solids until gas bubbles of sufficient size and number were formed to exert their bouyant force.

Comparison of Effect of Cloroben and Chlorine on Odors

It was thought of interest to make some preliminary experiments on the relative effect of Cloroben and chlorine on the odor production of sewage when incubated under anaerobic conditions.

Samples of sewage were treated with equivalent weights of Cloroben and chlorine amounting to 0, 5, 10, 20 and 40 p.p.m. and observations made from time to time on odor, H_2S production, turbidity, flocculation and pH.

A perusal of the results obtained indicates that even the smallest quantities of Cloroben masked the odors, but that there is no conclusive evidence that Cloroben reduced odor or H_2S production, with quantities up to 10 p.p.m., for more than two days. The same holds true for chlorine. After four days incubation considerable H_2S had been formed in the mixtures receiving 10 p.p.m. Cloroben or chlorine.

The addition of 20 p.p.m. Cloroben masked effectively and/or retarded anaerobic decomposition sufficiently to prevent odor production for four days. An equivalent quantity of chlorine reduced the odor somewhat after four days incubation. An amount of 40 p.p.m. Cloroben distinctly changed the original odor and this change persisted during the period of the experiment (five days). An equivalent quantity of chlorine gave a slight residual and prevented H_2S production but did not materially change the original sewage odor.

The preliminary evidence indicated that Cloroben had an original effect over chlorine in masking whatever odors were present and causing less dispersion of solids.

On the basis of the preliminary investigations further work was

conducted to determine whether small quantities of Cloroben intimately mixed with sewage were effective in preventing the production of hydrogen sulphide, and to note the effectiveness of Cloroben compared with chlorine.

As nearly as possible, the experiments were conducted to duplicate what occurs normally in sewers, *i.e.* the treatment with Cloroben and chlorine was followed after one hour detention by "re-seeding," by the addition of organisms capable of reducing sulphates to hydrogen sulphide, which normally are present in sewer films.

Procedure.—Cans containing 40 liters of strong sewage, collected from the Plainfield, N. J. sewage plant, were treated with 4 grams of ammonium sulphate and aerated violently for 30 minutes to remove most of the H_2S originally present. Portions of the sewage (500 c.c.) were treated with 10, 15 and 18 p.p.m. chlorine so that after 30 minutes standing these samples contained 0, 0.2 and 0.6 p.p.m. residual chlorine by the ortho-tolidine test. Four liters of sewage were then transferred into each of nine, 2 gal. carboys and treated as follows: Bottle No. 0, blank Nos. 1, 2, 3, and 4, treated with 5, 10, 15 and 30 p.p.m. chlorine or 33.3, 66.6 100 and 200 per cent of the chlorine demand, respectively. Bottle numbers 5, 6, 7 and 8 were treated with 5, 10, 15 and 30 p.p.m. Cloroben. After one hour, each bottle received 25 c.c. of a H_2S-free suspension culture of H_2S producing organisms. Ten minutes after the addition of the culture to the sewage the residual chlorine in bottles number 3 and 4 was 0.1 and 1.0 p.p.m. respectively. The treated sewages of each carboy were then transferred to stoppered bottles of about one-liter capacity. Care was taken to eliminate air bubbles. The bottles were incubated at 20–22° C. and at intervals the H_2S determined by transferring the contents of a bottle into a tube, making acid with HCl and determining the evolved H_2S.

Results.—The quantities of total sulphides, after 2, 4 and 5 days incubation in the untreated and treated sewage samples, are given in Table IX. The sewage samples contained initially considerable sul-

TABLE IX.—*Effect of Chlorine and Cloroben on Total Sulphides (Results in P.P.M.)*

Treatment, p.p.m.	0	5		10		15		30	
Days		Cl_2	Clor.	Cl_2	Clor.	Cl_2	Clor.	Cl_2	Clor.
0	1.44	0.0	1.2	0.0	1.1	0.0	1.2	0.0	1.1
2	14.0	7.3	5.0	4.7	4.3	2.75	4.3	0.4	3.3
4	30.9	25.1	10.0	16.3	12.1	12.7	10.1	4.7	5.2
5	30.9	34.6	20.2	25.9	14.1	12.6	12.8	6.6	7.3

phides, which even with 30 minutes violent aeration could not be completely removed. Undoubtedly most of the initial sulphides were present in combined form, such as CaS or FeS.

Sulphide production was very rapid in the control samples and after the fourth day apparently all inorganic sulphates had been reduced. The sulphate enrichment described in the procedure was equivalent to about 25 p.p.m. H_2S.

Treatment with 5 p.p.m. chlorine and Cloroben caused a marked reduction in sulphide production during the first few days. Cloroben appeared to have a greater retarding effect, which was maintained for a longer period. The same comparisons hold for the addition of 10 p.p.m., which for chlorine treatment represents an initial partial chlorination or a treatment of 67 per cent of the chlorine demand. The initial retardation was more pronounced with 10 p.p.m. chlorine treatment than with 5 p.p.m. With treatments equivalent to the chlorine demand (15 p.p.m.) there was little difference in the retarding effect of chlorine and Cloroben. It appears that the chlorine reacted with the combined sulphides, which accounts for the differences between chlorine and Cloroben treatment after two days.

It is important to note that approximately equal retardation was obtained during the first four days, regardless of whether the Cloroben treatment was 5, 10, or 15 p.p.m. With additions of 200 per cent of the chlorine demand only relatively small increased retardation took place.

The results in Table IX give the cumulative effect over rather long periods. Calculating the rate of sulphide production, particularly for periods more comparable to the time the sewage actually flows through the sewers, is perhaps of greater interest. Assuming the destruction of initial sulphides by chlorine and no destruction by Cloroben, the average rates of sulphide production per 12-hour interval has been computed and is shown in Table X.

TABLE X.—*Average Rate of Sulphide Production per 12 Hours*

Treatment, p.p.m.	0	5		10		15		30	
Hours		Cl_2	Clor.	Cl_2	Clor.	Cl_2	Clor.	Cl_2	Clor.
0–48	3.15	1.82	1.25	1.17	0.97	0.69	0.72	0.10	0.45
48–96	4.22	4.45	1.25	2.90	1.70	2.50	1.45	1.07	0.49
96–120	0.0	4.75	5.1	4.80	1.00	0.0	1.35	0.95	1.55

The average rate of sulphide production for either chlorine or Cloroben treatment was not constant, but decreased with dosage and increased with time. This is more clearly illustrated in Figure 5, where the rate of H_2S production per 12-hour periods is plotted against the dosage. The figures presented represent the mean rate at approximately half of the time intervals considered. For example, the average rate of H_2S production reported for 5 p.p.m. Cl_2 treatment for the first 48 hours was 1.82 p.p.m. per 12 hours, which was the approximate rate during the 18 to 30-hour interval. Since the rate was increasing with time it can be assumed that the rate from 0 to 18 hours

was less than 1.82 p.p.m. and likewise the rate from 18 to 48 hours was greater than 1.82 p.p.m. Thus in sewerage systems where the sewage flow is rapid, Cloroben treatment equivalent in weight to from 33.3 to 100 per cent of the chlorine demand, appears to be as effective as chlorine, and with treatment to 200 per cent of the chlorine demand,

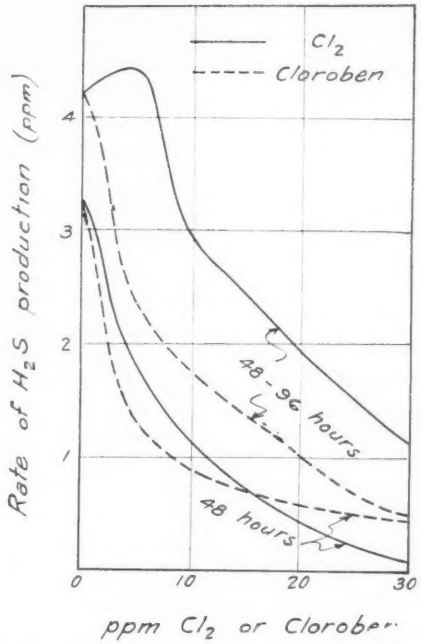

FIG. 5.—Effect of Cloroben and chlorine upon H_2S production of stale sewage.

the chlorine is somewhat more effective than Cloroben. Over longer periods of contact the Cloroben treatment appears to be more effective.

SUMMARY AND GENERAL CONCLUSIONS

Laboratory experiments were made to determine the effect of "Cloroben" (essentially ortho-di-chlorbenzene) upon the coagulation, odor control, settlability, bacterial reduction, aerobic decomposition, storage, and staleness of sewage; the effect of Cloroben upon the settling and compacting rate and biological activities (stimulation and retardation) of activated sludge; the effect on storage of fresh solids and activated sludge; the effect on sludge digestion; the comparative effect of chlorine and Cloroben on odor control; and the effect of distribution of Cloroben in sewage.

This preliminary work indicates in general that:

1. The odors produced by septic sewage, or present in open or closed sludge tanks, are masked by the addition of Cloroben.

2. Small quantities have no effect on anaerobic digestion. Larger quantities of Cloroben retard or inhibit it.

3. Large quantities of Cloroben retard the aerobic decomposition of sewage and sludge.

4. Cloroben in small amounts has little or no detrimental or stimulating effect on the efficiency of activated sludge.

5. Stored activated sludge is kept in "good condition" for at least five days and a clear supernatant may be decanted, with additions of 100 p.p.m. Cloroben. This treatment produces no apparent change in the settling properties of the sludge. Treatment with larger quantities of Cloroben kept the sludge in good condition for a longer period.

6. A Cloroben treatment of 13 p.p.m. permits storage of sewage for 25 days without septicity.

7. Cloroben does not prevent odors or septicity of fresh sewage solids for longer than three days when 1 per cent Cloroben (on dry solids basis) is added.

8. Cloroben has a temporary inhibitory effect on the digestion of properly seeded sludge.

9. Cloroben intimately mixed with sewage in quantities varying from 1/3 to 2 times the chlorine demand persistently retards sulphide production in sewage for four days or more. Compared with equivalent weights of chlorine (to satisfy 33 to 100 per cent of the chlorine demand) Cloroben is more effective than partial chlorination in preventing the formation of H_2S over periods of from 4 to 5 days.

10. Super-chlorination is more effective than an equivalent weight of Cloroben. Cloroben treatment should occur prior to sulphide production, *i.e.* while the sewage is fresh.

11. Chlorine destroys the initial sulphides, but retards sulphide production to a lesser extent than Cloroben.

12. Cloroben must be well distributed in sewage to prevent the coalescing and settling of the material.

13. By inhibiting anaerobic microbiological activity, with its attendant gas formation, which causes the solids to float and prevents compacting of sludge, Cloroben treatment affords an efficient means of obtaining a greater solids concentration in sludges.

14. Cloroben aids somewhat in the chemical dewatering of sludge.

Plant Operation

OPERATION OF SLUDGE GAS ENGINES*

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General

The installation of engines to use sludge gas for power has been gradual and has been developed along conservative lines. During the last four or five years, the development has been much more rapid than formerly.

As early as 1907, an engine was operated at a leper colony at Bombay, India, using sludge gas. This was, of course, a small installation and did not lead to any further development at that time.

About 1921, an engine of 25 brake H.P. was installed at Birmingham, England. This was so successful that a 150 H.P. engine was installed in 1927, followed by the installation in 1928 and 1930 of two more engines each of 400 H.P. Since that time, one 540 H.P. engine and two 120 H.P. engines have been installed at Birmingham.

Within the last five years, Berlin, Germany, has also taken advantage of the savings resulting from the use of sludge gas in engines. In one of their plants, there are two 500 H.P. and one 750 H.P. gas engines and in another plant, there is an additional 750 H.P. engine.

In this country, one of the earlier installations was at Charlotte, N. C. Most of the first installations were relatively small units and were made with engines normally used with gasoline and adapted, by minor changes, for the use of gas. The Charlotte engines were of this type. The first major installation of a strictly gas type of engine was that at Springfield, Illinois, installed in 1932 and started in operation in January of 1933.

The list of major gas engine installations has grown until it now comprises those shown in Table I. Within a few months, there will be nine installations in the United States of engines using sludge gas, with a total of 4292 installed horse power, ranging in size from 100 to 550 horse power. There are many smaller installations, in addition to those given in the list.

Gradual Development

When engines were first installed, engineers were handicapped by lack of definite information on the quantity of gas available, its rate of production and the variations in the rate of production, analyses of the gas including the heat content, the effect of hydrogen sulphide and

* Presented Before the Fall Meeting of the California Sewage Works Association, Palo Alto, September 23, 1935.

TABLE I.—*Installations of Engines Using Sludge Gas, September, 1935*

City	No. Units	Horse Power	Year Installed	Driving
Operating Prior to September, 1935				
Birmingham, England	1	150	1927	Generator
	1	400	1928	"
	1	400	1930	"
	1	540	1934	"
	2	120	1934	"
Berlin, Germany				
Wassmannsdorf Plant	1	750	Between	Generator
Stahnsdorf	2	500	1927 and	"
	1	750	1932	"
Charlotte, N. C.	1	225	1928	Blower
	1	75	1928	Pump
Rockville Center, N. Y.	1	30±	1930	Blower
	1	40±	1930	Generator
San Bernardino, Cal.	1	40	1930	Generator
Springfield, Ill.	1	180	1932	Blower
	1	157	1934	"
Los Angeles Co., Cal.	1	200	1935	Pump
Cedar Rapids, Iowa	1	230	1935	Generator
Proposed and Under Construction				
Madison, Wisconsin	1	230	1935	Blower
Ann Arbor, Mich.	1	120	1935	"
Peoria, Ill.	1	550	1935	"
	1	300	1935	Generator
Coney Island, N. Y.	3	300		Generator
District of Columbia	1	1200		Generator

other impurities, on engine parts, and the like. There is still need for more of such information, but the development has been along conservative lines.

The foregoing kind of information is also helpful in the selection of auxiliary equipment. In order to use the maximum of gas produced, it is necessary to provide some storage to level out the variations in the rates of production and use of the gas. In order to determine accurately the amount of storage required, it is necessary to have complete information on the variations in the rate of gas production.

Inasmuch as the composition of the gas varies at different plants and from day to day at the same plant, full information on gas analyses is helpful in estimating the value of a proposed installation. In the case of impurities, particularly hydrogen sulphide, it is essential to have a good record of gas analyses in order to determine whether or not the gas should be purified before being delivered to engines. With normal sewage, there has not been any evidence of corrosion of engine parts by hydrogen sulphide.

AUXILIARY EQUIPMENT

The auxiliary equipment usually installed with engines using sludge gas includes air starting equipment, heat recovery boilers, circulating

pumps, and occasionally oil purifying equipment. By the use of exhaust heat boilers, that portion of the heat in the gas not used for power may be largely recovered and used to heat digestion tanks and buildings. In this manner, from one-half to two-thirds or more of the available heat in the gas is put to useful purposes. Some additional cooling equipment is usually required to waste that portion of the heat not needed for heating purposes.

It appears proper in any installation of perhaps 100 H.P. or more to provide a centrifuge or other effective means of purifying the lubricating oil to eliminate the waste of oil which would otherwise result. It is often found that the oil purifying equipment can be used for the lubricating oil of other machinery about the plant.

Service to Which Engines Have Been Applied

Engines using sludge gas have been used to drive electric generators, air compressors and pumps. The engines at Birmingham, England, and Berlin, Germany, drive generators. In this country, the major installations have been in connection with activated sludge plants, and, therefore, engines have been generally used directly on air compressors. There are a few installations where engines are directly connected to centrifugal pumps. An installation of two 75 H.P. sludge gas engines for this service is now contemplated for Aurora, Illinois.

The characteristics of these various services are worthy of some comment. For generator drives, the engine generator unit operates usually considerably below full load most of the time and operates at constant speed. This simplifies the installation, in some respects, but results in poor fuel economy at partial load, due to the low mean effective pressure.

In driving a centrifugal pump, there is likely to be less variation in load, and the installation can be designed so that it will operate near the full load of the engine. This is usually a constant speed unit or very nearly so, and in that respect, is relatively simple.

In the direct drive of air compressors, the possibility of varying the speed offers opportunity of fuel economy but introduces difficulties with critical speeds. Such a design provides a unit of great flexibility which can be regulated to the amount of air required by variations in the quantity and characteristics of the sewage treated. It is a characteristic of positive displacement blowers which are usually used on such units that the horse power is directly proportional to the speed and so to the amount of air delivered. To the engine, this means that it will always operate at the mean effective pressure designed for full load. This results in fuel economy and high efficiency for all conditions. The speed variation, however, involves a problem of critical speeds which must receive very careful consideration by the designer.

Features of Design Affecting Operation

There are a number of features of engine design which more or less directly affect the operation of engines using sludge gas. This is particularly true because the engines so often are installed for 24-hour service.

When an engine is installed to drive an air compressor in an activated sludge plant, particularly if there is only one engine, it is important that it run continuously as nearly as possible. To accomplish this, those features of engine design which affect maintenance should be carefully considered. The item of valve grinding is a case in point. If the valves must be ground on the engine, it means that the engine must be out of service for a period of time sufficient to grind all of the valves. If, on the other hand, the valves are in removable cages or in the cylinder head, it is possible to remove the valve units of one cylinder and replace them with spare units in good condition and thus interrupt engine operation for only a few minutes. This can be done during a night shift or at any time when such a short interruption will be least harmful. In this manner, the service for which the engine is used can be maintained without the use of any auxiliary power. In the smaller engines, the valves are usually installed in the heads and in the larger ones, in valve cages. It is also desirable, in some cases, that the engine design be such that the cylinder heads can be readily removed and replaced without dismantling the manifolds or other parts.

Engines should be designed to permit easy access to connecting-rod bearings. Main bearings should be designed so that they can be renewed without removing the crank shaft. This requires that the lower bearing shall be secured in the supporting frame by means of end flanges rather than dowel pins so that its shell can be rotated around the shaft.

It appears to be advantageous, particularly in the larger engines, to use cylinder liners so that excess wear in the cylinder will require replacement of a liner only, rather than a complete cylinder. This is the type of construction which is now largely being used in the so-called box-frame type of engine.

The engine should be equipped with the ordinary safety devices which will automatically stop the engine in case of low oil pressure, excessive oil temperature, failure of cooling water supply or excessive temperature thereof. It is also advisable for the operator to make a routine check of the pressures in the various cylinders by a suitable pressure indicator. This is helpful in indicating the need for valve grinding.

When an engine is used to drive an air compressor, it is convenient and helpful to be able to operate the unit over a reasonable range of speed in order to give the maximum of flexibility in meeting the air requirements of the plant. Considering daily variations in load and the gradual building up of the load over a term of years, it is often found that a blower unit should have a range of speed from normal

down to 50 per cent of normal. This feature brings up the very important question of critical speeds. The problem is complicated by having the engine and blower direct connected. This means that the computations for critical speeds must include the rotating parts of both units rather than those of the engine alone. It is desirable, if not essential, that the major critical speeds be entirely avoided within the operating range of the unit. It is not always possible to avoid all the undesirable criticals. In that case, they should be carefully determined and marked on a suitable speed indicator so that the operator can avoid operation at the critical speeds.

Related to the question of critical speeds is that of vibration, in general. It is, of course, desirable to mount an engine on a foundation block, separate from any building foundation. In this way, the vibrations resulting from normal operation and from minor critical speeds are isolated from the building. A separate foundation block is not always possible. In that case, particular care must be taken to dampen vibrations by means of mass in the engine base, and in many cases, by using some insulating material such as cork or even a spring-mounting to isolate the engine from the building structure.

The continuous operation which is usually required of engines installed in sewage treatment plants points to the need of restricting the engine design to conservative limits. This involves such questions as speed both in R.P.M. and in piston speed, allowable mean effective pressure, bearing pressures, sizes of various parts, and in important installations, the experience of the manufacturer in designing and building engines of this type. It is known that the present tendency in engine design is toward higher speeds and, in some cases, to lighter weights. These developments have their proper place and have been accelerated by the introduction of the Diesel engine into locomotive service. For service in sewage treatment plants, however, it still appears best to use conservative designs. This will limit the piston speed to about 1000 or 1100 feet per minute and the brake mean effective pressure to about 70 pounds per square inch. It is considered good practice to limit the crank shaft diameter to not less than one half of the cylinder diameter.

The question of the number of cylinders should be considered according to the requirements of any particular job. It is well known that six-cylinder engines or those having any multiple of three above six generally have a finer balance and minimize vibration. Where an engine must be set on a building floor, it is, therefore, desirable to use six cylinders in order to reduce the problem of vibration control.

The choice between two and four-cycle engines involves the question of heat recovery. For recovering heat from exhaust gases for heating sludge tanks or buildings, a four-cycle engine is generally better than a two-cycle. A four-cycle engine will produce exhaust gases having temperatures from 700 degrees F. to 900 degrees F., while the exhaust gases from a two-cycle engine are more likely to be 300 degrees F. to 400 degrees F. because of the volume of scavenging air required.

Operating Results

Operating records from the major installations of sludge gas engines now in operation show the results to be expected.

Engines of this type and of conservative design may be expected to give continuous service with very little time out for maintenance and repair. Operation will be interrupted by valve maintenance and by various emergency repairs, most of which are minor in nature. These minor interruptions include replacing valve springs, replacing spark plugs, occasionally replacing a magneto, and the like. Where valves can be removed in assemblies, the maintenance of valves constitutes a minor interruption but if valves must be ground in place, this service will require an interruption of about one 8-hour shift every three or four months. It appears reasonable to expect, however, that engines of this type built on conservative lines and with proper attention in the design to those maintenance details involved in this particular service may be expected to remain in operation 95 to 98 per cent of the time.

To aid in maintaining continuous operation, certain spare parts should be kept ready for prompt replacements. A list of such parts should include spare spark plugs, one or two valve assemblies, valve springs, gaskets, magneto, and the like.

The cost of repairs and supplies for engines operating on sludge gas, provided the engines are of conservative design, may be expected to be relatively low. A common figure, used for estimating purposes, is $2.00 per brake horse power per year. Springfield, Illinois, reports for one year of operation a cost of $168.00, amounting to $1.40 per brake horse power per year. This includes $120.00 for labor of attendance which more than covers valve grinding. It would appear that with provision for and careful attention to cleaning the lubricating oil, the use of a gas free of or low in hydrogen sulphide and with due attention to other elements of good operation, this item can be kept within $2.00 per brake horse power per year.

An engine of this type is expected to produce, under an acceptance test, about one horse power hour for every 10,000 B.T.U. supplied in the fuel. The fuel rate will, of course, vary with the condition of the valves and the per cent of the full load. For sludge gas having an effective heat content of 600 B.T.U. per cubic foot, therefore, an engine will consume about 17 cubic feet per brake horse power hour. A test on the first engine installed at Springfield, Illinois, showed a gas consumption varying from 17.2 to 20.1 cubic feet per brake horse power hour for a mean effective pressure varying from 66.1 to 51.7 pounds per square inch. The engines at Birmingham, England and Berlin, Germany, were guaranteed to produce one brake horse power per 20 cubic feet of sludge gas.

The savings accomplished by some of the major installations are worthy of note. Birmingham reports that for the period of 1927 to 1933, inclusive, the value of power produced by the engines was 31,625 pounds sterling, and the total cost of operation including interest and

maintenance was 18,209 pounds, resulting in a net saving of 13,416 pounds for the period. In Germany, it is reported that several plants produce all the power required for operation, including in a number of cases power for aeration. Springfield, Illinois, reports that for 21 months of operation in 1933 and 1934 their 180 horse power engine has produced on the average 60,000 K.W.H. per month. They report: "During the past 21 months our operating expenses have been remarkably low, averaging less than $100 per month for interest, depreciation, oil, repairs, and materials, and labor of maintenance. So far as the engine alone is concerned, it has paid for itself two times in the one and three-quarter years."

Similar savings are indicated in studies which have been made on engine projects now being installed.

Summary

In summary, it may be said that the record of major installations of engines to use sludge gas, beginning at Birmingham, England and in Germany, and now making relatively rapid progress in the United States, has established the soundness of the general procedure of utilizing sludge gas for power. There is need for more data on gas production and characteristics in order to make wise selections, not only of engines but of auxiliary equipment. The nature of the service to which gas engines are applied indicates that conservative engine design should be used and due consideration given to elements of design affecting maintenance cost. Records of operation in England, Germany, and the United States show definite savings in the cost of sewage treatment plant operation by the installation of gas engines to use sludge gas for power.

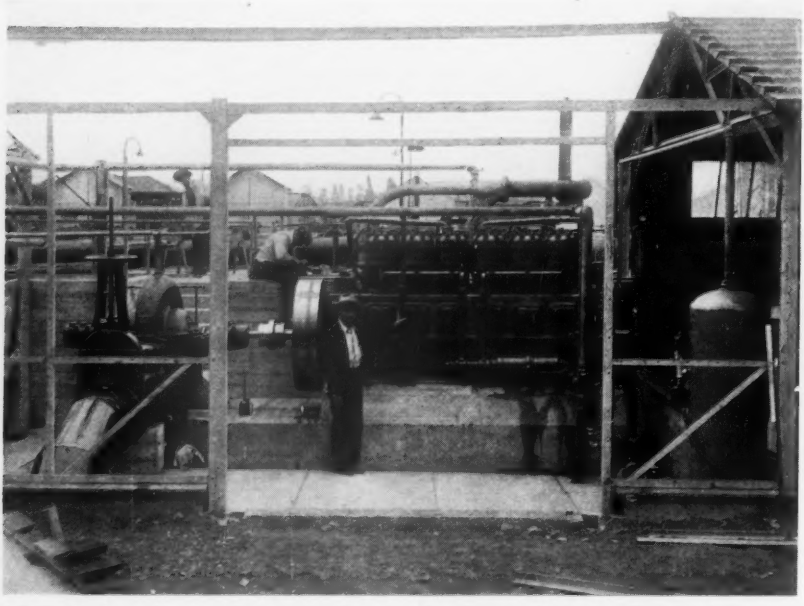
OPERATION OF A 200-HORSEPOWER GAS ENGINE USING SLUDGE GAS FOR FUEL *

By C. F. Tennant

Chief Operator, Los Angeles County Sanitation Districts

In recent years the gas engine has begun to assume a place of importance as a prime mover in sewage disposal plants, using the gases of sludge digestion as fuel. There are a number of such units in the United States and Europe which have been placed in successful operation during the past decade and which have demonstrated that the cost of power generated by such means can compete successfully with all but the very lowest electrical power rates. This paper discusses, from an operator's viewpoint, the first four months' experience with such an engine recently installed at a Southern California plant.

On May 4, 1935, a 200-horsepower Clark gas engine (Fig. 1) was



200-H.P. Clark engine installed at the Los Angeles County Sanitation Districts' Treatment Plant, using digester gas for fuel.

placed in service at the treatment plant of the Los Angeles County Sanitation Districts, to supply power for pumping the effluent through four miles of 36-inch concrete line at from 15 to 25 pounds pressure. The engine is of the vertical, 6-in-line type, of the conventional 4-cycle

* Presented Before the Fall Meeting of the California Sewage Works Association, Palo Alto, Sept. 23, 1935.

L head design, both valves being on one side and operated by a common cam shaft. The cylinders are 9-inch bore and extend low enough so that the skirt of the piston is never exposed. The pistons are of aluminum, have an 11-inch stroke and are each provided with five compression rings, two oil rings and one wiper ring. The compression ratio is 5.85 to 1, giving a compression pressure of 135 pounds per square inch. Oil is pumped through rifle drilled crank shaft and connecting rods to all working parts of the engine at 30 pounds pressure after being filtered and cooled. An independent auxiliary oil system supplies oil under pressure to the high pressure side of the cylinders. The ignition system consists of a single unit high tension magneto and airplane self-cleaning spark plugs set in the center of the head. The cooling water is pumped through 200 feet of 2-inch steel water pipe submerged in the effluent wet well. The average operating temperature of the cooling water is about 130 degrees F. The unit is housed in a low metal building and the summer sun exercises a strong influence upon the operating temperature. Operating speeds range from 370 to 550 R.P.M., developing from 70 to 200 H.P. The total daily power output is about 4000 H.P., hours.

The engine is started with air compressed to 185 pounds pressure by a small electrically driven unit. Starting is about as simple as starting a motor car, once the peculiarities of the gas and of the engine have been discovered. Our experience parallels that of Haseltine * as regards difficulty in starting due to changing gas quality. Sludge gas has a narrow firing range and the gas-air ratio must be nearly correct before combustion will occur; therefore it is essential that the starting unit have sufficient capacity to keep the engine in motion long enough for the operator to discover the firing range of the gas available at the time of starting. The gas-air ratio is easily changed by varying the air supply admitted through a butterfly choke valve in the air intake. The gas-air ratio is at times changed while the engine is operating as and when the gas quality varies sufficiently to indicate the desirability of such a change.

The engine is directly connected by a flexible coupling to a 22 by 18-inch Fairbanks-Morse, horizontal centrifugal pump. No clutch or other means of disengaging the pump and engine are provided. This arrangement works very well since the pump has very little drag until the engine gains momentum. The pump is of the bottom suction, split case type and when operated at top speed of 550 R.P.M. will deliver 12,500 gallons per minute at 25 pounds line pressure. When operated at the lowest operating speed of 375 R.P.M. the output is 6300 gallons per minute, permitting an operating range of 6200 gallons per minute. When used for pumping, the variable-speed feature of a gas engine is very convenient as compared with constant-speed electric motors. As the sewage flow varies, the pumping rate can be varied accordingly.

The fuel for this engine is the usual type digester gas, having a calorific value of about 650 B.T.U. per cubic foot. Its three most im-

* This Journal, 5, 3, May, 1933.

portant components are methane (68 per cent), carbon dioxide (31 per cent) and hydrogen sulphide never more than .02 per cent. These figures are approximate averages. The gas is obtained from a multi-stage digester erected at the Districts' Joint Disposal Plant, previously described to this Association.* An 8-inch pipe line 600 feet in length conveys the gas to the engine at about one-half pound pressure and at the engine the pressure is reduced to about one-quarter of a pound. The gas pipe line is laid to a minimum grade of one inch per hundred feet and a sump is provided at the engine end to remove the condensed moisture. No scrubbing or other means of purifying the gas is provided.

The gas consumption of the engine is 24 cu. ft. per H.P. hour when the engine is operating at 550 R.P.M. under full load and best efficiency. When the engine is slowed down to lower speeds the efficiency drops off to the point where 33 cu. ft. of gas may be required per H.P. hour. Since but about one-fifth of the heat value of the gas is converted to useful work in the engine, most of the remaining four-fifths could be available for heating the digester although such use is not practiced at present at this plant. Cooling water has an average temperature of 130 degrees F. when leaving the engine and exhaust gas, 310 degrees F. at the muffler. Some heat is lost between the engine and the muffler.

The sludge digestion tanks have a daily output of about 250,000 cu. ft. of gas. Since the engine consumes about 24 cu. ft. per H.P. hour the digester has a potential output of about 400 continuous H.P. if all the gas were used for power purposes. In addition to its use for power, the gas is also used as fuel to heat digester circulating water and in an incinerator to burn sewage skimmings and bar screenings. If an attempt were made to utilize fully the power possibilities of the digester, larger storage capacity would be necessary to store the peak production, or an auxiliary fuel supply provided to bridge the periods of minimum gas production. The gas supply from the digester fluctuates and at times it is necessary to shut off the incinerator to keep the engine in continuous service, but it has never been necessary to shut down the boiler.

The quality of the digester gas compares favorably with other gases which have been used successfully in power generation. When compared with the low grade group such as blast furnace, coke oven, etc., that have approximately 100 B.T.U. per cu. ft. and which permit a compression of 200 pounds or more and a gas-air ratio of 1 to 1, digester gas appears high in grade. When contrasted with rich, natural gas with a B.T.U. value of 1200 and a gas-air ratio of 12 to 1, digester gas value suffers somewhat. It is, however, well above the poorest, about half as good as the best, occupying about the center of the scale in value.

After the engine had been in continuous service for 375 hours the cylinder heads were removed and the valves were examined. There was no corrosion of the valves and no carbon deposits in the cylinder

* This Journal, 3, 4, Oct., 1931—A. M. Rawn; *California Sewage Works Journal*, **6**, 1, 1933—A. M. Rawn.

heads or upon the pistons. The combustion chamber was clean. Tappets are inspected for clearance once a week and the gap is maintained at .005 inch with the valves at full heat. Tappets are easily accessible upon this engine and setting can be accomplished at 500 R.P.M. Accessibility of important working parts is a feature that should be carefully considered in a unit that is expected to render continuous service. The unit under discussion has been operated continuously for 1,000 hours at a stretch.

Oil used in the engine is a high grade motor type recommended by the engine manufacturers and known commercially as Triton S.A.E. 30. Analyses of the oil drained from the circulating system indicates that some 2,000 hours or three months of operation may be obtained between crank case drainings. The oil shows a slow tendency toward acidification which is an important indicator of its condition. Unusual concentration of hydrogen sulphide in the fuel gas will probably accelerate acidification. Conditions noted here are for a gas of the analyses stated. The oil consumption is about 1 gallon per 5,450 H.P.Hr.

Costs.—The cost of the engine in place was about $7,000. A motor to take its place would have cost, in place, $2,700, a difference in first cost of $4,300 in favor of the motor. The Districts have the Clark Engine distributors in Los Angeles under contract to maintain the engine (excepting spark plug and magneto replacements) for five years at .03 cents per H.P.Hr. developed. Operation costs other than the maintenance contract cost are .01 cent for oil and .0733 cent for attendance and spark plugs, per H.P.Hr.,—a total of .1133 cent per H.P.Hr. A rate of 15 per cent is assumed for interest and depreciation for the engine.

Electric power at the plant would cost .53 cent per H.P.Hr. if the engine were supplanted with an electrically driven motor. Assuming this power rate, the prevailing load factor under which the unit operates and 10 per cent for interest and depreciation for the motor, the over-all costs for engine or motor will be identical in the period May 4, 1935, to Feb. 15, 1936; that is the engine will have paid its additional first cost by Feb. 15, 1936. Calculated another way, the engine is at present showing a saving in operating costs of nearly $460 per month, an amount which increases as the load factor increases. Extending this reasoning to the average daily output of gas from the digestion tanks, it may be stated that the digester gas at the Joint Disposal Plant has a value of about $920 per month or 14.4 cents per 1,000 cu. ft. if applied as internal combustion engine fuel to develop power.

When it was first announced that a gas engine was to be installed at the Joint Disposal Plant, some doubt was expressed by the plant operators who anticipated increased duties and trouble with this new departure in power generation, but as time passes and the engine continues to give dependable service, doubt is yielding to confidence and admiration. It appears to be a sound, practical investment and its use and extension limited only by the gas supply.

I. THE PALO ALTO SEWAGE TREATMENT PLANT*

By Harvey O. Banks

Formerly Chief Plant Operator

Historical

Prior to July, 1934, when the new sewage treatment plant was placed in operation, the sewage from both the city of Palo Alto and Stanford University discharged, untreated, into the Mayfield slough. Two outfall sewers from the city and one from the university discharged at a point about three-quarters of a mile up the slough from San Francisco Bay proper. Another outfall sewer from the Mayfield District of the city discharged at a point about one-third of a mile farther up the slough.

During recent years, the city of Palo Alto has spent several hundred thousand dollars in developing the Bay Front lands and the slough for recreational and other purposes. The Yacht Harbor, which was built several years ago, is now used extensively. It is expected that more recreational facilities, such as a salt water swimming pool and a salt water lake for boating, will be developed in this area as fast as funds become available. The Palto Alto Airport, completed within the past year, is located on the Bay Front lands a short distance away from the site of the sewage treatment plant and within a fifth of a mile of the slough.

The Yacht Harbor anchorage and club house are located about 800 feet down the slough from the first point of sewage discharge mentioned above. About 800 feet above this point is the Palo Alto Boat Works. It is obvious that the discharge of untreated sewage into the slough constituted a very serious health menace. Floating sewage solids rendered the water around the Yacht Harbor quite offensive at times, and gas from the decomposition within the sludge banks deposited in the channel created a serious odor nuisance.

The situation had become so serious that in May, 1933, a proposal for a $90,000 bond issue for sewerage improvements was put up for vote and was approved. Proceedings were immediately instituted to obtain a grant of about $29,000 from the PWA. This was approved in December, 1933.

In order to correct the situation, the problem of disposal of the sewage from the university as well as the city had to be considered. The logical thing was to combine the sewage from the university and the city and to treat and dispose of the combined flow. Accordingly, an agreement was made with the university whereby the City of Palo Alto was to finance and build a new outfall sewer system and treatment plant to take care of the combined sewage flows. The university agreed to pay a proportionate share of the fixed charges and operating costs of

* Presented Before the Fall Meeting of the California Sewage Works Association, Palo Alto, Calif., Sept. 23, 1935.

the new system and treatment plant based on the ratio of average flow from the university to the average combined flow.

The only other possible method for the final disposal of the sewage, except emptying it into the slough, was to build a long outfall sewer across the mud flats and to carry the sewage out to the bay. Under the conditions, it was felt that plain sedimentation would be sufficient preliminary treatment, since the outfall could be carried out several hundred feet beyond the shore line where there would be ample water for dilution at all times.

Palo Alto Sewage Treatment Works. Showing exterior of pump house, mechanical rake and clarifier.

At first, it was planned to pump the raw sludge from the clarifier over to the garbage dump, which is located near the proposed site of the plant, and to dispose of sludge with the garbage by the fill-and-cover method. There were some objections to this, and when it became apparent that a PWA grant could be obtained, the plans for the treatment plant were revised to include a heated digester, gas collection, gas engine and electric generator, the cooling water from the engine to be used in heating the digester.

The existing outfall sewers of both Stanford University and Palo Alto were badly overloaded. Consequently, an entirely new outfall sewer system was included in the plans for sewerage improvements as well as the treatment plant and the outfall line from the plant out to the bay.

Construction was started about the middle of December, 1933. By July 1, 1934, the construction of the new sewers and the outfall line to the bay had been completed, and the construction of the plant had progressed far enough so that the basic parts of the plant—pumping plant, clarifier, and digester—could be placed in service at that time. By the end of September the construction work was complete except for the gas engine-generator set which was not installed until March, 1935.

General

The City of Palo Alto is mainly residential in character, with a population according to the 1930 census of 17,000. The city has separate sanitary and storm water sewer systems. There is one large cannery in the city which cans tomatoes, peaches, pears, etc., according to the season. With this exception, and the usual number of garages and laundries, the sewage from the city is entirely domestic in character.

The population of Stanford University is estimated at 5,000. It also has separate sanitary and storm water sewers. The sewage is, of course, entirely domestic, although rather dilute due to the heavy use of showers in the gymnasiums and dormitories. The average sewage flow from the university is 0.489 m.g.d., or about 97 gallons per capita per day.

At the plant, the sewage flow has varied from a minimum of 0.9 m.g.d. to a maximum of 2.5 m.g.d. when the cannery is running. The average sewage flow is 1.545 m.g.d., or 74 gallons per capita per day based on estimated contributory population of 21,000. Judging from pump operation, the maximum rate of sewage flow seldom rises above 4 m.g.d.

The raw sewage as received at the plant is still quite fresh, with a pH of 7.3 to 7.6. It has the following characteristics:

	Average	Maximum	Minimum
Suspended Solids	333 p.p.m.	680 p.p.m.	170 p.p.m.
B. O. D.	340 p.p.m.	720 p.p.m.	160 p.p.m.
Settleable Solids	18.1 c.c./l.	45 c.c./l.	

The values for suspended solids and B.O.D. are based on composited samples taken every two hours for 24 hours, while the settleable solids determinations were made on catch samples.

Description of Plant and Operating Data

The treatment plant is located about two miles from the city limits on the reclaimed Bay Front lands. The sewage is brought to the plant by gravity through a 27-inch vitrified outfall. The elevation of the invert of this outfall at the plant is — 10.9 below mean high tide.

The plant was designed to have ample capacity for the probable increase in population during the next ten years, with a maximum capacity of 3 m.g.d. Provision was made in the design and construction of the plant for the addition of another pump, a second clarifier, and a second digester when needed. It now consists of the following units:

(1) Combined bar screen and grit chamber mechanically cleaned.
(2) Pumping plant.
(3) Clarifier with sludge removal mechanism.
(4) Sludge pump.
(5) Heated digester.

(6) Sludge drying beds.
(7) Gas holder.
(8) Gas engine and generator.

Combined Grit Chamber and Bar Screen.—The sewage passes first through a Link-Belt mechanically cleaned grit pit and bar screen. When the plant was built a 1-inch clear opening bar screen was installed. The mechanical apparatus for cleaning the screen and pit was not installed until about three months after the plant was first started. The original intention was to operate for a time without the mechanical rake, which could be installed at any time, and to rake the screen by hand, not attempting to clean the grit pit at all. It was soon found, however, that, with the 1-inch clear opening screen and the inefficiency of hand raking, rags and sticks passed through the screen to such an extent that the pumps became clogged five to ten times per week. Sticks and other objects which passed through the sewage pumps often clogged the sludge pump. With the advent of the tomato canning season, a tremendous amount of tomato peelings was brought down to the plant. These piled up on the screen so fast that the operator had to spend about one-third of his time raking the screen.

After about two months of this experience, it was decided to install a ¾-inch clear opening bar screen instead of the 1-inch screen and to install mechanical apparatus for raking the screen and cleaning the grit pit. After this was done, the trouble largely disappeared. Clogging of the pumps now happens very infrequently. The raking mechanism is electrically controlled and is entirely automatic in operation. It is set to rake the screen once every nine minutes.

The amount of screenings and grit is not large. It averages about 100 gallons per day, and often runs as high as 200 gallons per day when the cannery is running. The screenings are stored in garbage cans and twice a day the cans are hauled to the garbage dump and there disposed of by fill-and-cover method.

Pumping Plant.—From the grit pit and screen chamber, the sewage flows into the wet well from which it is pumped to the clarifier. The pumps are located in a pump pit beside the wet well. The flow line of the pump pit is 4.25 feet above the bottom of the wet well.

The pumps are of the horizontal, single suction, closed impeller, non-clogging type, manufactured by the DeLaval Steam Turbine Company, with 6-inch suction and 5-inch discharge. The suction piping as installed is 8-inch and the discharge piping is 10-inches. The pumps are driven by 10 h.p., 220 volt, 865 r.p.m. Crocker-Wheeler motors.

Since the pumps cannot be started until the level of the sewage in the wet well is higher than the top of the pump casings, thereby priming the pumps, they are equipped with Fisher air relief valves placed on the top of the casings. The pumps work against a static head varying from about 17 to 22.5 feet. The friction head is about 5 feet. The pumps are rated at 1100 g.p.m. against a 25 foot total head with an efficiency of 75 per cent.

Normally the pumps are entirely automatic in their operation, although they can be controlled manually if necessary. The automatic control is obtained through the use of the Roto-Trol mechanism as manufactured by the Water Levels Control Company. This mechanism is actuated by the changes in air pressure in a piece of 4-inch pipe fastened vertically, open end down, on the wall of the wet well, as the level of the sewage in the wet pit rises and falls. The changes in air pressure are transmitted to the mechanism by copper tubing. By an expanding bellows and lever arrangement, these pressure variations cause rotation of a disk on which are mounted mercury contacts, two for each pump, one for starting and one for stopping, which control the operation. The pumps are set to cut in and out as the rate of sewage flow increases or decreases.

At the present time, three pumps are installed. Provision was made for the installation of a fourth pump whenever necessary. The suction and discharge piping for the fourth pump are complete in place outside the pump pit and extend through the walls of the pit.

To date, the third pump has cut in very infrequently and then only for a few minutes at a time.

Clarifier.—The clarifier is circular in shape, 55 feet in diameter, with a water depth of 7.5 feet at the side and 9.6 feet at the center. It is equipped with a Hardinge plow type sludge removal and surface skimming mechanism. The skimmer part of the mechanism had to be altered several times before it would function efficiently. In designing the clarifier, the customary truss type of support for the sludge removal machinery was dispensed with, and two 30-inch I-beams were substituted. This gives the clarifier a much more attractive appearance.

The sewage flows across the clarifier from a series of inlets spaced along a peripheral length of 45 feet to a peripheral weir opposite, which has a crest length of 45 feet. The operating data for the clarifier are as follows. With one pump running, or with a rate of flow through the clarifier of 1.58 m.g.d., the overflow rate is 666 gal. per sq. ft. per day, and the theoretical detention period is 2.25 hrs.

The following table gives the average operating results:

	Raw Sewage	Clarified Effluent	% Reduction
Suspended Solids	333 p.p.m.	156 p.p.m.	53.1
B. O. D.	340 p.p.m.	231 p.p.m.	32.1
2 hr. Settleable Solids	18.1 c.c./l.	1.06 c.c./l.	94.2

Disposal of the Clarified Effluent.—The clarified effluent passes first through a 16-inch Sparling main line meter which serves to record the total volume of sewage. Incidentally, this meter has to be cleaned of rags etc. about twice a month. After the meter, the sewage passes into a 22-inch wood stave outfall. This outfall, which is 4660 feet long, discharges the effluent into San Francisco Bay at a point about 725 feet offshore.

Sludge Disposal.—Normally, the raw sludge and skimmings are drawn from the clarifier once every two hours. It is sometimes necessary to draw more often, particularly during the canning season. The sludge and skimmings are drawn off into a pit which has been calibrated so that the volume drawn can be measured and recorded each time. A 4-inch Marlow plunger type sludge pump pumps the sludge to the digester. The data pertaining to the raw sludge are as follows:

	Average	Maximum
Volume	6890 gal./day	19025 gal./day
% Solids	5.34	10.10
Dry Solids	2050 lb./m.g.	5880 lb./m.g.
% Volatile Matter in Dry Solids	77.6	91.6
Volatile Matter	2390 lb./day	5340 lb./day

Digester.—The digester is of the circular patented Hewitt type with a spherical top and conical bottom. It is 50 feet in diameter, 37 feet deep at the center and 25 feet deep at the sides, and has a capacity of about 52,000 cubic feet. It was designed on the basis of 1.5 cu. ft. capacity per capita. The digester is equipped with a gas collection dome with water seal. Overflow liquor can be drawn off from any one of four different levels in the digester. The lowest level from which it can be drawn is about mid-depth. The overflow piping is so arranged that the liquor can be returned to the raw sewage at the wet well, or it can be recirculated by means of the sludge pump through the raw sludge inlets at the top of the digester.

The digester is heated by the cooling water from the gas engine which will be described later. The cooling water is circulated through three coils of 2½-inch pipe suspended on the digester wall at about mid-depth.

As the gas engine was not installed until last March, the digester had to be operated without heat for nine months. During that period, the temperature of the digesting sludge varied from 60° F. to 75.5° F. depending on the season. After heat was first applied in March, the temperature rose gradually to about 100° F. in about four months. Due to the fact that the engine has had to be shut down several times for rearrangements, repairs, inspection, etc., the temperature has varied considerably. The maximum temperature reached was 101° F., which occurred after the engine had been running steadily for three months. On August 4, the gas engine was shut down in order to install a new generator and has not been operated since. During this shut-down, the digester temperature has fallen from 101° F. to 83° F.

Whether or not the present arrangement will supply heat enough to keep the temperature at a high value during the cold winter season is open to question. It may be necessary to install a heat exchanger in the exhaust pipe of the engine in order to get more heat to the digester.

As stated above, the average daily charge of raw sludge to the digester has been about 6890 gallons, with an average volatile matter content of 2390 pounds.

The digester was started without being seeded with ripe sludge. No lime was used. The pH rose to 7.0 in about nine months after it was first started and stands at 7.1–7.2 now. Soon after starting, the cannery season opened, and large quantities of cannery waste—peach fuzz, waste peach slices, tomato peelings and seeds, and pear peelings were pumped into the digester. The digester was thus badly overloaded right at the most inopportune time. Subsequently, a great deal of trouble was experienced with foaming, but this corrected itself in time. The tomato peelings formed a heavy, fibrous layer at the top of the digesting sludge. This seemed to be the cause of most of the foaming.

Disposal of Digested Sludge.—While the digester was being operated unheated, the digested sludge had a moisture content of 93.7 per cent, and the volatile matter content of the dried solids was 67.7 per cent. This indicated that the sludge as drawn was only partly digested, and that the digester does not have adequate capacity for unheated digestion. In August, after the digester had been heated for about four months, the moisture content of the digested sludge was 94 per cent and the volatile matter content of the dry solids had fallen to 54 per cent, indicating a much higher degree of digestion. The digester has not been operated long enough under any particular set of conditions to be able to give any reliable data on the results of digestion. The figures given are purely indicative.

For dewatering the digested sludge, a series of sludge beds were prepared by cleaning off, leveling, and throwing up dikes on some of the ground surrounding the plant. The soil is not especially suited for sludge dewatering, as it is not very pervious. However, since a large area has been prepared and more beds can be quickly and cheaply made if necessary, the sludge can be allowed to remain on the beds until thoroughly dry.

A few experiments have been conducted to find whether the dried sludge can be successfully used for fertilizer on the city lawns and parks. A small disintegrator is used to reduce the sludge particles to a size suitable for fertilizer purposes. Several small experimental plots have been seeded with grass, using other types of fertilizer as well as the sludge. Preliminary results indicate that it can be used successfully. It appears to be the equal of mushroom manure and seems to be ideal for mulching purposes. The sludge contains large numbers of tomato seeds, but this does not seem to be objectionable, as the young tomato plants die out after they have been cut once with a mower. No attempt has been made to sell any of the dried sludge as yet.

Gas Production and Collection.—The accompanying table gives the data concerning the production of gas by the digesting sludge. It will be noted that gas was first produced in measurable quantities in September, 1934, two months after the first sludge was pumped into the digester. The rate of gas production gradually increased from September to April, 1935, with an average daily production during April

of 38,430 cubic feet per day, or 1.83 cubic feet per capita per day. Up to the last week in March, the digester was operated unheated. After April the rate of production declined gradually until the average daily volume produced in September, 1935, was 24,350 cubic feet. This decline in gas production may be due, in part, to the change in internal conditions resulting from the application of heat to the digesting sludge and in part to the establishment of more or less average conditions after the irregularities of the period during which normal digestion was being established.

The maximum volume of gas produced during any one day has been about 52,000 cubic feet, or 2.5 cubic feet per capita per day.

Gas Production, Palo Alto

Month	Total Vol. Produced	Av. Vol. Produced per Day	Av. Rate of Production per Capita per Day	Vol. Matter Added During Month	Vol. of Gas Produced per Lb. Vol. Matter Added	Av. Digester Temp.	Remarks
	Cu.Ft.	Cu.Ft.	Cu.Ft.	Lb.	Cu.Ft.	° F.	
1934							
Sept.	19,131	616	0.03	62,620	0.35	——	Digester Unheated.
Oct.	160,550	5,350	0.26	68,460	2.3	——	" "
Nov.	243,880	7,860	0.37	68,790	3.5	——	" "
Dec.	286,600	9,550	0.46	58,650	4.9	——	" "
1935							
Jan.	436,400	14,080	0.67	91,200	4.8	64.6	" "
Feb.	788,300	25,430	1.21	90,860	8.7	——	" "
Mar.	875,800	31,300	1.49	89,260	9.8	60	Gas Engine Started Mar. 22.
April	1,192,000	38,430	1.83	83,080	14.3	72.3	Digester Heated.
May	798,559	26,620	1.27	66,570	12.0	79	" "
June	867,600	28,000	1.33	63,430	13.7	92.2	" "
July	642,100	21,400	1.02	55,350	11.6	95.7	" "
Aug.	801,200	25,850	1.23	68,355	11.7	97	Gas Engine Stopped Aug. 4.
Sept.	754,900	24,350	1.16	——	——	86.2	Digester Unheated.

Based on an estimated contributory population of 21,000.

During July and August, 1935, with an average temperature of the digesting sludge of about 96.3° F., 11.65 cubic feet of gas were produced per pound of volatile matter added to the digester. The average gas production per capita per day was 1.12 cubic feet. As the digester had been heated prior to July for a period long enough to establish normal conditions for heated digestion, the above figures probably approximate the average gas production to be expected for heated digestion. To date, the digester has not been operated long enough under any one given set of conditions to give any really reliable figures on gas production. From the records available at the present time, it is evident that an average daily production of at least 1.0 cubic feet per capita may be expected.

An analysis of the gas, made in April, 1935, gave a heat value of 588 B.T.U. per cubic foot. No other analyses of the gas have been made.

A floating gas holder with a maximum capacity of 3,000 cubic feet is used in the gas collection system to take care of the variations in the rate of gas production. At times of maximum rates of gas production, the capacity of this holder has been entirely inadequate, and large amounts of gas have escaped from the holder. The holder maintains a constant pressure of 11 inches of water on the gas system.

As much of the gas as possible is used as outlined below. The excess is burned in a waste burner.

Gas Utilization.—In March, 1935, a gas engine and generator were installed at the plant to use the digester gas as a source of power for generating electricity to run the plant.

The gas is also used for heating the laboratory and office and for the laboratory burners. A gas line was run from the plant to the Palo Alto Airport, which is located near the plant. The gas is used there for heating. It is intended to make some experiments in the near future in the use of the digester gas in gas beacons for lighting the Airport and landing field.

To date, the use of the digester gas for the purposes outlined above has been most satisfactory. No corrosive or deleterious effects have been noted. The only trouble has been that not enough water traps were installed, and our meters sometimes fill up with water and must be emptied. Blow-offs have been put on the gas lines.

Laboratory.—The laboratory and office are located on the second floor of the pump house over the pump pit. The laboratory is equipped with apparatus to run the standard tests usually run at a plant of this kind, i.e. suspended solids, B.O.D., settleable solids, sludge moisture, and volatile matter. It is hoped that the laboratory can be equipped for gas analysis in the near future.

Landscaping and Architectural Treatment.—Considerable attention has been devoted to the problem of making the plant as attractive as possible. To this end, the grounds around the plant have been carefully laid out and graded. Surfaced paths have been made connecting the various parts of the plant. The remainder of the grounds has been laid out with lawns and shrubbery.

In order to harmonize with the conventional type of California architecture, the buildings have red tile roofs and are finished with a tan stucco effect. The interiors of the buildings have been painted according to an attractive color scheme.

The exposed concrete work of the clarifier was also given a coat of tan stucco. The metal superstructure of the clarifier, the gas holder, and the exposed portions of the mechanical rake apparatus were painted with an aluminum asphalt paint. All other exposed metal surfaces have been painted with Inertol. All exposed painted surfaces are given a new coat of paint at least twice a year.

Power Requirements.—The total possible connected load of the plant at the present time is 40 h.p., including the three sewage pump motors and the motors on the mechanical rake, clarifier mechanism, sludge pump, and fresh water well pump. At present, only 30 h.p. are

connected, as one of the three sewage pumps is usually left disconnected, since two pumps are sufficient to handle the present sewage flow.

The average power consumption has been 133 kw. hr. per m.g., exclusive of lights, or 205 kw. hr. per day. At times of maximum flow, the power consumption may run as high as 320 kw. hr. per day. About 12 kw. hr. per day are used for lights and the laboratory oven, etc.

At utility rates, the average cost is about $132 per month, or $2.95 per m.g. It is expected that the use of the gas engine-generator set will cut this power cost by at least 75 per cent.

Operation.—The plant is operated by three shifts per day of eight hours each. The chief operator takes the day shift from 8:00 A.M. to 4:00 P.M. and all laboratory work is done during this shift. All other routine work around the plant—cleaning, oiling, tending to the lawns and shrubbery, etc., is divided between the other two shifts.

It is intended to keep a technically trained man in charge of the plant at all times. The slight additional cost of obtaining such technical supervision is felt to be entirely justified and may be more than compensated by other economies in operation which would not be possible with less capable personnel.

Complete operating and cost records are kept at all times. The operating data, which are recorded each day, include the following:

(1) The daily volume of sewage flow
(2) Volume of screenings removed
(3) Volume of raw sludge removed from the clarifier and pumped to the digester.
(4) Average per cent moisture and average volatile matter in the raw sludge
(5) Power used
(6) Power generated
(7) Power used for lights
(8) Volume of fresh water used
(9) Volume of gas used by gas engine
(10) Volume of gas used for heating
(11) Volume of gas burned in waste burner
(12) Number of hours that gas engine was run and amount of lubricating oil used

Observations on the following are taken two or three times during each week:

(1) pH of digester overflow liquor
(2) pH of raw sewage
(3) pH of raw sludge
(4) Temperature of digesting sludge
(5) Temperature of raw sewage
(6) Temperature of raw sludge

Whenever digested sludge is drawn from the digester, a composite sample is taken, and tests are run to determine per cent moisture and the volatile matter content of the dry solids.

Twice a week, samples of the raw sewage and effluent are taken every two hours over a 24-hour period and are composited. The volume of samples taken is proportional to the rate of flow passing through the clarifier at that time. Suspended solids and five-day B.O.D. tests are run on the composite samples. Also, twice a week, two-hour settleable solids tests are run on catch samples of the raw sewage and effluent. These catch samples of the raw sewage and effluent for settleable solids tests are taken at 11:00 A.M. and 1:00 P.M. respectively.

A sample of the raw sludge is taken each time sludge is drawn from the clarifier. These samples are composited over a 24-hour period.

Treatment of Cannery Wastes.—Soon after the plant was started in July, 1934, trouble descended upon it in the form of cannery waste. The Palo Alto plant of the Sutter Packing Company cans about 150 tons of tomatoes per day; about 200 tons of peaches per day; about 100 tions of apricots per day; and about 100 tons of spinach per day during the respective seasons. Between 0.5 and 0.8 m.g. of water are used daily during the canning seasons. At the time the plant was started, all of the refuse from the canning operation was being dumped into the sewers. The plant was entirely incapable of handling this totally unexpected extra load. The tomato peelings and peach fuzz often formed layers of scum six inches or more in thickness on the surface of the clarifier. The clarifier skimmer was totally unable to remove this scum, and it had to be removed by hand with long handled rakes. All of the cannery waste was pumped to the digester. This was undoubtedly responsible for most of the foaming which occurred later.

As soon as it became evident that the plant would be unable to handle the cannery waste, an effort was made to determine whether at least part of the cannery waste could be disposed of by some method other than dumping it into the sewers. The cannery has co-operated fully in solving this problem.

The following measures have been taken and have proved effective in preventing the cannery refuse from entering the sewers. All floor drains at the cannery are screened with one-inch mesh screening, and all washings from the floor must pass through two of these screens before reaching the sewer. The screenings are collected and hauled to the garbage dump. When tomatoes are canned, bad tomatoes and cuttings from defective tomatoes as well as peelings are passed through a "Cyclone Beater," which separates the juice from the more fibrous material. The juice passes through a screen with openings 1/16-inch in diameter and drains to the sewer. The fibrous material left is hauled to the garbage dump. In canning peaches, the lye solution used for peeling still drains to the sewer, but the large particles are separated out by the mechanism described above. Refuse from the

spinach pack is caught on the floor drain screens and is hauled to the dump.

Of course, the sewage treatment plant still receives the liquid waste from the cannery, but, due to the effectiveness of the above measures, very little fibrous material reaches the plant. It seems to be able to handle the liquid waste quite satisfactorily.

Thanks to the splendid co-operation of the Sutter Packing Company, it is believed that the problem of cannery waste has been solved. The company has been put to some expense involved in the installation of the "Cyclone Beater" and the floor drain screens and in hauling the fibrous refuse to the garbage dump, but no complaint has been made.

Costs

Construction Costs.—The total construction cost of the plant, exclusive of the new outfall sewer system and the outfall line to the bay, was $63,323.82, or a unit cost of about $21,100 per m.g. of design capacity. The 22-inch wood stave outfall line cost $19,760.61.

Operating Costs.—For the nine-month period from July, 1934, to March, 1935, inclusive, during which the gas engine-generator set was not operating, the average operating costs, exclusive of fixed charges, were as follows:

	Per M.G.	Per Month
Labor and Supervision	$ 6.76	$302.45
Power	2.95	131.86
Supplies	2.20	98.36
Maintenance	0.33	14.90
Overhead	0.65	28.90
Total	$12.89	$576.56

The average rate of sewage flow during this period was 1.476 m.g. per day.

The gas engine-generator set operated almost continuously during the three months of April, May, and June, 1935. During this period, a total of 22,180 kw. hr. of electricity was used by the plant. Of this total, 17,710 kw. hr., or 79.9 per cent, was generated at the plant, using digester gas as a source of power. For these three months, the average operating costs, exclusive of fixed charges, were as given in the table below:

	Per M.G.	Per Month
Labor and Supervision	$ 5.95	$299.20
Cost of Power Purchased	1.01	51.05
Supplies	3.02	151.88
Maintenance	0.07	3.40
Overhead	0.61	30.66
Total	$10.66	$536.19

The average rate of sewage flow was 1.641 m.g. per day for the period.

No conclusive comparison of operating costs with and without the use of the gas engine-generator set can be made based on the above

figures, as the use of the gas engine was still in the experimental stage. For this reason, no attempt was made to keep an account of the extra costs of maintenance and supplies strictly chargeable to the cost of power generation. The increase in cost of supplies for the second period, for instance, was not entirely chargeable to the use of the gas engine and generator. The saving due to the generation of electricity at the plant probably averaged about $1.50 per m.g. while the experimental set-up was in operation. This saving will be greater with the permanent arrangement for the generation of power, which has just been installed.

Conclusion

The plant was designed by Mr. J. F. Byxbee, City Engineer, and his associates on the staff of the City Engineering Department. It was built by force account as PWA Project No. 1256 with Mr. Fabian Miller, Assistant City Engineer, as Construction Superintendent. The writer acted as Assistant Field Engineer and Inspector during the construction and was Chief Operator from July to September, 1934, and from January to May, 1935. At the present time, Mr. Jack Kimball is Chief Operator.

II. GENERATION OF ELECTRICITY AT PALO ALTO WITH A GAS ENGINE

The generation of electricity at the Palo Alto Sewage Treatment Plant with a gas engine, using digester gas as fuel, has three distinct objectives, namely: (1) It provides a second source of power for operating the plant. The sewage must be pumped from the incoming sewer in order to reach the outfall line which is about 11 feet higher. It is, therefore, imperative that two sources of power be provided at the plant, each of which may act as a stand-by for the other. (2) It reduces the power costs. (3) The digester must be heated in order to provide for the proper digestion of the sludge. The use of the cooling water from the gas engine is an easy and economical way of heating the digester. Otherwise, it would be necessary to provide a gas-fired boiler.

Power Requirements of the Plant.—The total possible connected load at the plant is 40 h.p., including the three sewage pump motors at 10 h.p. each, and the motors on the screen rake, clarifier, sludge pump, and fresh water well pump. Of this total, only 30 h.p. need be kept connected at the present time, as only two of the three sewage pumps are required to handle the present sewage flow.

Experimental Work.—The city had on hand a heavy duty gasoline engine which had been purchased for other purposes, but which had never been used. In order to save the cost of a new gas engine, it was decided to attempt to remodel this gasoline engine to use digester gas as fuel and to make a temporary experimental installation at the sewage plant in order to determine the feasibility of power generation with this

remodeled engine. The main objectives of the experimental work were:

(*a*) To determine whether or not the engine would work satisfactorily on digester gas.
(*b*) To determine how much corrosion of the engine parts would be caused by the gas.
(*c*) To determine whether or not it would be necessary to clean the gas before use.
(*d*) To determine whether or not the engine would develop power enough to carry the plant load.
(*e*) To determine the probable reduction in power costs.
(*f*) To determine whether or not there would be enough heat available in the cooling water for heating the digester and to determine the effect of heating on the digestion of the sludge.
(*g*) To determine how much gas would be used, and whether or not there would be enough gas generated to supply the engine after the digester had been heated for some time.

The engine was originally a heavy-duty, four cylinder, four cycle, gasoline engine, manufactured by the Model Engine Company, Pittsburgh, Pennsylvania. The bore is 5½ inches and the stroke 6½ inches. It is rated at 65 h.p. at 600 r.p.m., using gasoline as fuel, and is complete with clutch and governor.

The engine was remodeled for the use of digester gas as fuel by Mr. D. McLachlan, Chief Engineer of the Palo Alto Water Works. The compression ratio was raised about 10 per cent. An Ensign gas carburetor was installed, and long-bodied spark plugs were used.

The city did not have a spare 220 volt generator, but there was a spare 20 h.p., 1160 r.p.m., 220 v., 3 ph., 60 cycle motor available. For the experimental work, it was decided to use the motor as a generator rather than buy a new generator. The motor was connected to the gas engine through a V-belt drive with pulleys so proportioned that the motor was driven at 1200 r.p.m., when the engine was running at 600 r.p.m. The motor was then connected into the power circuit of the plant.

With the motor being driven at about 40 r.p.m. over the normal speed, it became a generator. It generated, of course, only as long as there was voltage on the line from the main power supply. The power output of the motor-generator was constant as long as the speed remained constant. If the output at any particular time was greater than the requirements of the plant, the excess was forced back into the main line, and conversely, if the power required by the plant was greater than the output, then power was drawn from the main line. Variations in output were secured by increasing or decreasing the speed of the engine.

A water trap, gas meter and a 1-inch R.G.T gas filter were installed on the gas feed line to the engine. No other gas cleaning devices were used. The gas supply was under a pressure of 11 inches of water.

The cooling water system of the engine was connected to the heating coils of the digester. Circulation of the cooling water was provided by the engine water pump.

This set-up was placed in operation March 22, 1935, and ran almost continuously until August 5. It was in operation a total of 2,475 hours. During this time, 23,700 kwh. were generated, equivalent to an average output of 9.6 kw. From March 22 to August 5, 3,564 kwh. were purchased. Thus, while the engine was in actual operation only 76.4 per cent of the total time for the period, 86.9 per cent of the total power required by the plant during the same period was generated by the engine-generator set. The average output of 9.6 kw., while more than enough to satisfy the average power demand of the plant, was not quite enough to carry two sewage pump motors plus the remainder of the plant. However, it was found that the engine had ample reserve power to step the output up to 14 kw. by increasing the speed slightly.

The average gas consumption by the engine was 571 cubic feet per hour, or about 60 cubic feet per kwh.

The engine used an average of five quarts of oil per day. This was not all burned, as there is considerable leakage from this particular engine. Triton S.A.E. No. 30 oil was used.

The engine was torn down for inspection and such repairs as might be necessary after it had been running steadily for about two months. The valves were found to be badly burned and warped due to the excessive heat. They were replaced with tungsten-vanadium steel valves. New spark plugs were also put in. No evidence of corrosion or pitting due to the use of the digester gas was found.

The engine was torn down again after it was stopped on August 4. This time the valves were found to be in good shape, but again the spark plugs were badly burned. As before, absolutely no evidences of pitting or corrosion were found. Apparently, there had been no more wear than there would have been had the engine been operating on gasoline.

The results of the use of the cooling water of the gas engine for heating the digester may be summarized as follows: It was found that the cooling water supplied ample heat to keep the digester at a temperature between 90° and 100° F. during the summer months. If more heat than the cooling water can supply is needed for heating the digester during the cold winter months, a heat exchanger can be installed on the exhaust pipe of the engine. This, it is believed, will provide ample heat to keep the digester at a relatively high uniform temperature throughout the year.

A very marked improvement in sludge digestion was noted while the digester temperature was held between 90° and 100° F.

The gas production by the digesting sludge declined somewhat as the temperature went up. The volume of gas produced per day never dropped below 20,000 cu. ft., which is more than enough to supply the engine for continuous operation plus the other uses of the gas for heating.

Permanent Set-up.—The results of the experimental work were so satisfactory that it was decided to make a permanent installation using this same engine and a generator. A 30 kva., 220 v., 1,200 r.p.m. generator was obtained and connected to the engine. It was immediately found that, when running at 600 r.p.m., the engine would not develop power enough to carry the maximum plant load. The engine speed was stepped up to 700 r.p.m., leaving the generator at 1,200 r.p.m. At this speed the engine will develop enough power to carry the maximum plant load easily. While this speed is somewhat above the design speed for the engine, it is believed that, with a little more care, the engine will be able to stand it.

This arrangement, of course, provides stand-by service in the event of failure of the main power supply.

The records of only nine days of operation of this permanent installation are available. The data for this period are:—

Total running time—126.5 hours.
Total power generated—1,640 kwh.
Average power output—12.96 kwh.
Gas consumption—667 cu. ft. per hour = 51.4 cu. ft. per kwh.

These figures indicate that the efficiency of the engine-generator set is somewhat higher than the efficiency of the engine-motor set. While it is running, the engine-generator set carries the full load of the plant. The electrical circuits for the plant are so arranged that the plant load can be thrown either onto the main line power supply or onto the engine-generator set through the use of a two-way master switch.

Estimated Savings in Power Costs.—It is estimated that the set will be run about 22 hours a day, and that the valves will have to be ground about once a month. The valve grinding job can easily be done by one man in 8 hours. The engine, therefore, will be operating about 94 per cent of the time.

As stated above, the cost, at utility rates, of the power used by the plant averages about $2.95 per m.g. The saving in power costs through the use of the gas engine and generator will be 94 per cent of $2.95 or $2.77.

The engine uses about five quarts of oil per day at a cost of 15 cents per quart. Assuming an average rate of sewage flow of 1.5 m.g.d., the cost of lubricants for the engine will be $0.50 per m.g. Repairs for the engine are estimated to cost about $0.15 per m.g.

The net saving, exclusive of fixed charges, which will be obtained through the use of the gas engine and generator for generating power will be about $2.12 per m.g., or $1,170 per year, under present conditions.

Conclusion

The generation of electricity at the Palo Alto Sewage Treatment Plant with a remodeled gasoline engine, using digester gas for fuel, is felt to be a highly successful and economical procedure. Between

90 and 95 per cent of the power required for operating the plant can be generated at the plant resulting in a net saving of $1,170 per year at the present time.

The use of the gas engine will also furnish a means of heating the digester through the use of the engine cooling water. This will result in greatly improved sludge digestion.

The ability to generate power at the plant will provide stand-by service in case of failure of the main power supply from the outside.

The remodeled gasoline engine which is being used is, of course, quite inefficient when using digester gas as fuel. Considerably more power could be developed, with the same gas consumption, if an engine which had been designed for gas were to be used. However, the present engine has ample power to carry the plant load for some time to come, and there is more than enough gas available. When more power than the present engine can supply is required, a larger and better gas engine will be installed, but until then, it is cheaper to use the remodeled engine.

The present supply of gas is enough to develop about 50 per cent more power than is now being generated.

Most of the credit for the success of the work which has been done at Palo Alto towards the generation of power from digester gas should go to Mr. Duncan McLachlan, Chief Engineer of the Palo Alto Water Works.

MINNEAPOLIS–SAINT PAUL SEWAGE DISPOSAL PROJECT *

By George J. Schroepfer

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Historical Review.—In view of the large amount of preliminary information that was secured by various investigators concerning the condition of the Mississippi River and remedial measures, this paper would not be complete without a brief review of the early history of the project. The condition of the Mississippi River was a subject of concern to many as early as fifteen or twenty years ago, but it was not until 1923 that any official recognition was given to the condition of the river. In that year the State Board of Health addressed communications to the City Councils of Minneapolis and Saint Paul, calling their attention to the situation and urging that steps be taken immediately to improve the condition of the river. No action having been taken on this communication, a similar one was addressed to the City Councils in 1925. Partly as a result of these communications and the interest taken in the project by civic groups, a Joint Interim Committee of the Minnesota and Wisconsin Legislatures was appointed, which enlisted the services of the United States Public Health Services in an investigation of the Mississippi River. This investigation covered the period from June, 1926, to August, 1927. The 1927 session of the Minnesota Legislature passed an act providing for the creation of the Metropolitan Drainage Commission with power to study and recommend means of alleviating the offensive river conditions. This Commission functioned continuously from June, 1927, to November 1, 1933, and investigated a number of phases of the sewage disposal problem, including the determination of the present and future quantities and characteristics of the sewage, the collection and analysis of samples from a long stretch of the Mississippi River, studies of the type and degree of treatment to be installed, and investigations of thirty alternate projects with variations, with consideration being given to eight possible treatment plant sites. As a result of its six-year investigation of the problem, the Drainage Commission recommended a combined system for the Twin Cities with a single treatment plant in the Pig's Eye Lake district below Saint Paul. The preliminary investigations made by this commission were of great value in expediting the work of the Sanitary District after its organization. The Board of Trustees of the Sanitary District, soon after its organization, adopted the plan which had been recommended by the Drainage Commission denoted as Project I_{10}, adopted the general plans for this project prepared by the Commission as its comprehensive plan and adopted one of three

* Presented Before the Eighth Annual Convention of the Central States Sewage Works Association, Urbana, Ill., Oct. 26, 1935 (Brought up to date as of Jan. 3, 1936).

programs of procedure and work which had been investigated by the Commission.

Salient Features of the Project.—At the 1929 and 1931 sessions of the Minnesota Legislature, bills were introduced providing for the creation of a Sanitary District, but it was not until the 1933 session that the Sanitary District Act (Chapter 341, Minnesota Session Laws of 1933) was passed. This act authorized the creation of a sanitary district embracing Minneapolis and Saint Paul, with provision for contracting with satellite communities, and provided for a Board of Trustees made up of three members from each of the two cities and one from the State at large. The act provides for the apportionment of costs on the following basis: works used exclusively by each city to be built and paid for by that city; works used in common to be apportioned as to construction costs on the basis of assessed valuations of the two cities and as to operation and maintenance costs on the relative sewage volumes contributed by the two cities. The Act necessarily divides the project into three main divisions: the works used exclusively by Minneapolis, which are estimated to cost approximately $3,240,000; the works used exclusively by Saint Paul, estimated to cost approximately $2,350,000; and the works used in common, consisting of intercepting sewers estimated to cost $6,315,000, and treatment works estimated to cost $3,375,000. The total estimated construction cost of the project is approximately $15,300,000.

The intercepting sewer project involves the collection of the sewage from the two cities, conducted to the intercepting sewers by approximately 1,200 miles of existing lateral and trunk sewers, which have a combined capacity at the outlets of 18,000 cubic feet per second. In connection with the construction of the project, approximately fifty-three miles of branch and main intercepting sewers will be built, of which approximately seventeen miles will be used exclusively by Minneapolis, 20.5 miles exclusively by Saint Paul, nine miles in common by the two cities and 6.7 miles of state and federal and future connections. The sewers vary in size, the smallest having a diameter of six inches, the largest being a 13 ft. 10 in. diameter section having a capacity of 947 cubic feet per second. By way of comparison, this is approximately two times the low river discharge at Minneapolis. While all the works are being constructed in accordance with a comprehensive plan prepared by the Sanitary District, it is only over the works used in common that the Sanitary District has direct control and supervision. The project is being financed by a loan and grant from the Federal Emergency Administration of Public Works. Up to the present time, however, no loans have been made from the Federal Government because of the low interest rate it has been possible to secure from private sources, most of the bonds having been sold at rates of 3.5 per cent or under.

Present Status of Project.—Construction of the Twin City sewage disposal project was begun July 13, 1934. At this writing, 33 major construction contracts totaling $6,580,134.81 have been awarded by the

District and the Twin Cities, of which 17 for a total of $4,595,339.26 are under District supervision, 7 for a total of $1,079,135.55 are under City of Minneapolis supervision, and 9 for a total of $805,600.00 are under City of Saint Paul supervision. All the work is being done under contract except that under direction of the City of Minneapolis which is being done by the city under a well established and directed day-labor system.

Only a small amount of work remains to be awarded on the intercepting sewers used in common, amounting to an estimated total of approximately $800,000. A total of approximately 88 per cent of length of the intercepting sewers used in common has already been awarded. Up to October 1, 1935, a total of $2,500,000 of construction work had been completed. In connection with the treatment plant, one contract for the screen and grit chambers has been let and plans and specifications are in preparation for the remainder of the plant. It is the expectation that the project will be completed by the spring of 1937.

It may be of interest to those connected with similar projects to describe briefly some of the interesting features and unusual conditions encountered in the construction of the intercepting sewers. The major part of the intercepting sewer is located in St. Peter sandstone, which material has, in general, very little cementing material and is at different depths and locations of widely varying characteristics. In some locations it has been possible to excavate the tunnel without sheeting or bracing of any kind and other places relatively tight sheeting and heavy timbering have been required to insure the stability of the excavation. The major portion of the work, however, has been timbered, by methods considered by the contractors to be best adaptable to the conditions that were encountered on their particular jobs. A number of ingenious methods of construction have been developed on the several jobs, chief among which is the method of transportation and removal of the tunnel muck. Instead of the usual and customary practice of mucking the sand either by hand or with suitable mucking machines, loading on cars and hoisting to the surface, the sandstone after being loosened (Fig. 1) is pumped to the surface by suitably designed pumps having rubber-lined impellers and casings (Fig. 2). The method described briefly consists in sluicing the loosened material to the intake of the pumps, which raise the material and water in some cases 200 feet to the surface of the ground. Relatively large quantities of water have been encountered on various jobs. The maximum rate of pumping on any one job was approximately 4,000 gallons per minute, and the total of the maximum rates on four sandstone tunnels amounted to as much as 15,000,000 gallons per day.

Type of Treatment Plant.—(*A*) The Engineers of the Minneapolis-Saint Paul Sanitary District have made investigations of the type of treatment to be employed on this project since the organization of the District in 1933. In connection with these investigations, the data that had been assembled by the Metropolitan Drainage Commission were

valuable. The Engineering Board * in a report to the Board of Trustees dated October 22, 1934, recommended that chemical treatment be adopted as the type of plant best suited to the Minneapolis-Saint Paul

FIG. 1.—St. Peter sandstone encountered in majority of Minneapolis-St. Paul sewers, and procedure used for its excavation and removal.

project. This report was reviewed by three consulting engineers, Mr. Cunningham of the firm of Fuller and McClintock, Mr. Greeley of Greeley and Hansen, and Mr. Townsend of Consoer, Townsend and Quinlan. Two of these consulting engineers, namely, Mr. Cunningham and Mr. Greeley, concurred in the recommendations of the Engineering Board. In this connection it should be mentioned that the engineers of the Sanitary District, as a result of both their independent and cooperative studies with the Engineering Board, were in whole-hearted agreement with the type of treatment recommended. All of the consulting engineers concurred in the recommendation to the engineering board as to degree of treatment necessary. The Board of Trustees on December 18, 1934, adopted chemical treatment for the Twin City project. On December 19, 1935, the Board, on recommendation of the Engineer, after review by Consulting Engineers Professor Bass and the firm of Fuller and McClintock, adopted a general plant layout and basic operating rates for design.

In the investigation of various methods and degrees of treatment, thorough consideration was given to the present and future require-

* Engineering Board appointed by PWA comprising C. W. Kutz, Chairman, Professor Frederic Bass and William N. Carey.

ments of the Mississippi River, in connection with which the large amount of data on the river collected from 1926 to 1934 was extremely valuable. The Mississippi River fluctuates widely both as to character-

FIG. 2.—Pumps used for lifting disintegrated sandstone to the surface.

istics and rate of flow necessitating, for reasons of desirability and economy, a type of treatment easily adjustable to the dilution requirements. An excellent and thorough investigation of the degree of treatment made under the direction of J. A. Childs, deceased, Sanitary Engineer of the District, indicated that under conditions of minimum stream flow, a reduction of approximately 70 per cent in biochemical oxygen demand would be necessary to maintain satisfactory conditions in the Mississippi River. An analysis of chemical treatment for all the sewage as against activated sludge treatment for a portion of the sewage, to obtain an overall reduction of 70 per cent, indicated marked economies in both first cost and total annual charges in favor of chemical treatment.

The sewage treatment plant will consist essentially of plain sedimentation augmented infrequently at times of low river discharge by chemical treatment. The frequency with which chemical treatment will be necessary is shown by the following. Considering discharges which occurred from 1892 to 1934, inclusive, and the 1945 estimated pollution load, studies indicate that, except for approximately 12 per cent of the time, plain sedimentation alone will suffice to maintain satisfactory

conditions in the river. Only during this relatively small percentage of time will chemical precipitation be necessary.

(*B*) *Description of Plant Proposed.*—The plant will be designed for the estimated 1945 flow of 134 million gallons per day from an estimated tributary population of 910,000. The main features of the treatment plant are shown in Figure 3. The treatment process will consist essen-

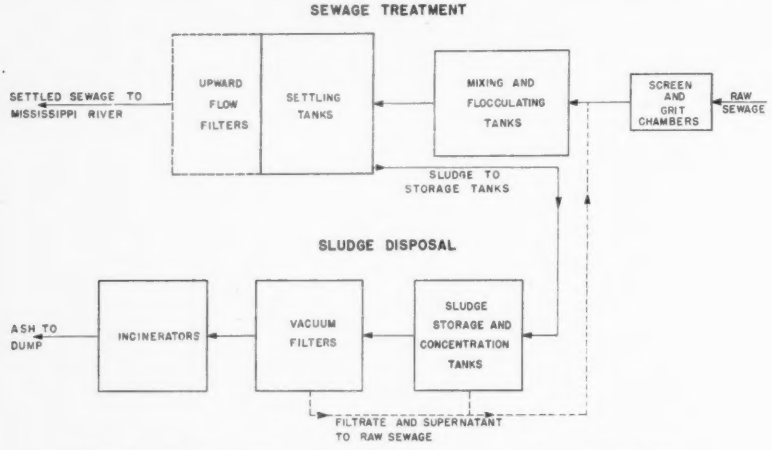

FIG. 3.—Flow diagram for parallel operation of treatment plant.

tially of screens and grit chambers, mixing and flocculating tanks, settling tanks, and possibly sewage filters, and the sludge disposal process will consist of storage and concentration, vacuum filtration, and incineration. While all of the details of the design have not as yet been settled, the main features of the plant have been sufficiently developed and decided upon to afford a tentative presentation at this time of basic design assumptions. In view of the magnitude of the project, in relation to the few operating chemical treatment plants and the rapidly changing status of sewage treatment, considerable thought has been given to flexibility and adaptability to developments which are likely to arise in the future.

It is estimated that the following average overall reductions will be effected by the plant. During times when sedimentation alone is employed a removal of 58 per cent in suspended solids and 37 per cent in five-day B.O.D. is expected. The addition of filters is expected to increase these removals to 74 per cent and 47 per cent respectively. With chemical treatment the removal of suspended solids is estimated at 83 per cent and of five-day B.O.D. at 70 per cent. Filters are estimated to increase these percentages to 90 and 75 per cent respectively.

The various features of the design were determined after consideration of existing local conditions and requirements; the writer wishes expressly to point out that varying conditions in other projects render many of the operating rates and design assumptions inapplicable. The various units of the plant are described in more detail as follows:

(*a*) *Screen and Grit Chambers.*—Upon entrance to the plant the sewage passes through two hand-cleaned coarse bar racks with 6 in. clear openings following which are four mechanically cleaned bar screens having 1 in. clear openings. After passing through the screens the sewage will enter the eight grit chambers which are approximately 12 ft. wide 10 ft. deep and 65 ft. long. The velocity of flow through the chambers will be 1.18 ft. per sec. at 610 m.g.d. and .45 ft. per sec. at 100 m.g.d. with all chambers in service. The grit will be removed by mechanical scraping mechanisms and will be washed by means of screw conveyors. The screenings will be incinerated either with or without shredding, dependent on the type of incinerator. The grit will be disposed of by dumping, for the present at least, with future operation studies to determine the economy and desirability of grit incineration.

(*b*) *Venturi Meters.*—After the screen and grit chambers the sewage will flow through two 108 in. by 60 in. Venturi meters, where the flow will be measured, and the flow so determined utilized in proportioning costs between the two cities as well as for distribution of flow through the various batteries of the plant, and for various operating purposes.

(*c*) *Mixing and Flocculating Tanks.*—Mixing and flocculating tanks will be designed for a total detention period of approximately 26 minutes, of which approximately 3 minutes will be devoted to mixing and 23 minutes to flocculation. Air mixing and flocculation will be employed, with the possibility of providing mechanical flocculation in the lower portion of the tanks. The flocculating tanks will be equipped with sludge scraping mechanisms so that they can be utilized as settling tanks during the relatively long periods between chemical treatment. The flocculating tanks are also so arranged that they can be used for post-chlorination during such times as chemical treatment is not required.

(*d*) *Settling Tanks.*—The settling tanks are to be designed for a detention period of approximately 120 minutes during such times as chemical treatment is employed and, by the utilization of the mixing and flocculating tanks during operation under plain sedimentation, a detention period of about 2.43 hours will be secured. The tanks are arranged for parallel operation alone but series operation can be effected in the future, if found desirable, by the modification of channels.

(*e*) *Sewage Filters.*—Alternate proposals will be received with and without filters. The filters, if of the magnetite sand type, will be designed for a rate of approximately 3 gallons per square foot per minute, based on average flow conditions. They would be installed as units integral with the settling tanks, or as separate units.

(*f*) *Sludge Storage and Concentration Tanks.*—The sludge, after being removed from the settling tanks, will be pumped to two sludge storage and concentration tanks with a total capacity for two days' storage on the average quantity of sludge produced during plain sedimentation, which is equivalent to approximately 30 hours during times of peak chemical treatment. During ordinary operation the period of

storage will be that needed for thickening, sampling and measuring the sludge.

(*g*) *Vacuum Filters.*—The installed capacity of the vacuum filters will be based upon a rate of approximately 5 lb. of dry solids per square foot per hour, using a quantity of sludge equal to 200 per cent of average quantity of sludge (including conditioning chemicals), produced during sedimentation treatment. The average gross rate with 24-hour operation and no units down for repairs will therefore be approximately 2.5 lb. per square foot per hour. The corresponding rate with chemical treatment is 4 lb. per square foot per hour. The filters will have capacity for approximately 180 tons of dry solids per day.

(*h*) *Incinerators.*—The incinerators will be designed for approximately 180 tons of dry solids per day (sludge and chemicals), which is based upon a capacity equal to 200 per cent of the cake production during sedimentation treatment. It is estimated that the sludge during sedimentation treatment will have a B.t.u. content per pound of dry solids (including conditioning chemicals) of 6,500 and during chemical treatment of 4,650. Various types of incinerators are under consideration.

(*i*) *Chlorination.*—In addition to its use in connection with chlorination of copperas, chlorination for disinfection will be practiced during the summer season with a dosage of 10 p.p.m. when chemical treatment is not employed and a total dosage of 16 parts per million during chemical treatment.

(*j*) *Chemical Handling and Feeding.*—Investigation of present price quotations indicates that a combination of chlorinated copperas, chlorine and lime will be the most economical chemicals for use at this plant.

Present plans provide for copperas and lime to be received loose on the spur track in the chemical building located over the grit chambers. These chemicals will be unloaded by pneumatic conveyors into overhead hopper bottom concrete storage bins having a capacity of about 700 tons copperas (approximately 15 days' supply) and 300 tons of lime (approximately 7 days).

On the operating floor underneath the storage bins there will be five identical and interchangeable gravimetric type dry chemical feeders, of which two ordinarily will be used for copperas, two for lime, and one will be a spare. The feeder will be equipped with indicators and recorders. There will be three jet-type solution chambers for copperas and two continuous type lime slakers. The copperas solution will flow to a small closed reaction tank where chlorine solution will be added in the ratio of one pound chlorine to eight pounds copperas plus an excess for disinfection when pre-chlorination is desirable. The chemical solutions will flow by gravity to the points of application in the mixing tank.

(*k*) *Chemical Dosages for Sewage Treatment.*—The chemical feeding equipment is being designed for dosage of approximately 85 parts per million of chlorinated copperas, 75 parts per million of lime and 16

parts per million of chlorine. The actual dosages as an ordinary operating routine are expected to be considerably less than these quantities.

(*l*) *Sludge Conditioning.*—Chlorinated copperas and lime will be used for sludge conditioning.

The work of the Sanitary District is under the direction of C. C. Wilbur, Chief Engineer, and the sewers used exclusively by each city are under the direction of the City Engineers, Fred T. Paul of Minneapolis and George M. Shepard of Saint Paul. William N. Carey is Project Engineer of the Federal Emergency Administration of Public Works.

MAGNETITE FILTERS IN SEWAGE TREATMENT *

By S. I. Zack

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In the past few years considerable information has been obtained by Filtration Equipment Corporation in co-operation with engineers of various municipalities on the performance and application of magnetite filters. The data indicate the practicability of mechanically straining out solids which normally are discharged over the weirs of the ordinary primary or secondary sedimentation tank.

Biologic filters composed of coarse and fine stone have been used for a good many years. Their development is associated with nitrification of organic matter rather than as a means of filtering out suspended solids. These filters slough off, producing solids which are extremely difficult to settle out even by means of humus tanks which usually follow. The effectiveness of sand filters for the removal of suspended solids has been more pronounced. Since it has been necessary to operate sand filters at low rates, requiring large areas, with frequent elimination from service for cleaning due to clogging, their use has not become widespread for the purpose of straining out solids.

The magnetite filter, developed during the past five years, provides a means of rapid mechanical filtration with a positive device for automatically keeping the bed clean.

Since the magnetite filter has been adequately described in previous publications there is no need for repetition here.

Operating Experience

In general, the following includes a comprehensive summary of published and heretofore unpublished data covering the results of about: 4 years at Dearborn on chemical treatment; 1 year at Coney Island on primary sedimentation and chemical treatment, where a tank with a magnetite filter was operated in parallel with a plain sedimentation tank not so equipped; 7 months on settling and filtering of activated sludge aeration liquor at the North Side Treatment works of the Sanitary District of Chicago; 6 months with and without chemicals at Perth Amboy, New Jersey; and 6 months in connection with trickling filters at Atlanta, Georgia. The results of these investigations furnish analytical and engineering data to serve as a basis for establishing the appropriate application and design of magnetite filters for any particular set of local conditions.

At the present time, the magnetite filter is considered to be merely a device for mechanical removal of suspended solids and improving tank hydraulics. Any reduction in B.O.D. would be the result of the

* Presented Before the Eighth Annual Convention of the Central States Sewage Works Association, Urbana, Illinois, October 26, 1935. Brought up to date as of January 1, 1936.

value of a corresponding amount of suspended solids in terms of B.O.D. and might vary for different sewages. Therefore results on the basis of suspended solids removal is principally dealt with. B.O.D. results are included in some cases.

Magnetite Filters and Primary Sedimentation

Coney Island.—The following shows a summary of the investigations on filtering of primary effluent carried out at Coney Island in cooperation with the Department of Sanitation of New York. Two 6 ft. diameter tanks were used, one plain tank and the other one equipped with a magnetite filter. Due to limited pump capacity, parallel operation was discontinued during Test No. 20–C and 20–D for the purpose of operating the magnetite filter at high rates. Tests No. 20–B, C, and D each represent 60 or more hours of continuous operation at filter rates above normal. The other tests represent operation for 3 to 7 days. Loss of head through the magnetite filter ranged between 1 and 2.5 inches. No clogging was experienced and the filter remained self-cleaning.

Table I.—*Parallel Operation—No Chemicals Added—Comparing Plain Sedimentation Tank with Filter Equipped Sedimentation Tank*

Test No.	Detention Period Hrs.		Filter Rate Gal. Sq. Ft. Per Min.	Suspended Solids				
				Parts per Million Pct. Removed				
				Raw Sewage	Effluent		Settler	Filter
	Settler	Filter			Settler	Filter		
4	2.25	1.92	0.95	142	60	40	58	72
5	1.21	1.11	3.28	105	66	38	37	64
7	1.01	1.01	3.33	73	49	31	33	58
8	2.00	2.02	1.81	105	59	26	44	75
11	0.98	1.00	1.84	89	65	37	27	58
11–a	1.98	1.93	1.89	117	72	44	38	62
20–a	2.00	2.00	1.84	56	42	22	25	61
20–b	1.00	1.00	3.73	102	82	46	20	55
20–c		1.81	4.02	119	—	54	—	55
20–d		1.23	5.96	129	—	61	—	56

Even with the short sedimentation periods preceding the filter and the high filter rates, the effluent was better than from longer periods of detention in plain sedimentation. However, the fact that the magnetite filter remains operative at these high rates of filtration is more important than the quality of effluent obtained, since it affords the flexibility necessary for meeting storm flow conditions.

Table II compares the average results of plain and filter settlers according to two groups of approximately equal detention periods.

One hour sedimentation followed by filtration at the rate of about

3 gal. per sq. ft. per min. resulted in a better effluent than approximately 2 hours of sedimentation without filtration.

TABLE II.—*Comparison of Removals—Plain Sedimentation Tank with Filter Equipped Settling Tank—Parallel Operation—No Chemicals Added—1 and 2 hr. Detention*

	Settler	Filter	Settler	Filter
Detention Period	2.05	1.97	1.05	1.03
Filter Rate gal./sq. ft./min	—	1.62	—	3.04
Susp. Solids p.p.m. Raw Sewage	105	105	92	92
Effluent	58	33	66	38
Removal	47	72	26	54
Pct. Removed	45	69	29	59

Perth Amboy.—Table III shows the results of twenty-eight days operation when the clarifiers equipped with magnetite filters at Perth Amboy were operated without chemicals. In this tabulation are shown only those days when the liquor below the filter was also sampled.

TABLE III.—*Perth Amboy-Mechanical Filtration of Settled Sewage. Results of Operation When No Chemicals Used*

Date	Flow	Suspended Solids					5-Day B.O.D.				
		Raw Sewage	Under Filter	Filtered Effluent	p.p.m. Rem. by Filter	Pct. Overall Reduct.	Raw Sewage	Under Filter	Filt. Final Eff.	p.p.m. Rem. by Filter	Pct. Overall Reduct.
Sept. 7	3.03	216	140	49	91	77	244	246	134	112	44
8	2.80	138	88	56	32	59	179	164	107	57	40
9	3.86	236	110	85	25	64	153	169	126	43	18
10	3.38	128	118	73	45	43	246	225	151	74	38
15	2.60	174	92	44	46	75	293	153	123	30	58
16	2.76	294	148	96	52	68	382	265	220	35	42
17	3.07	426	144	88	56	79	472	189	161	28	66
18	2.53	284	122	78	44	73	259	117	125	8	52
19	2.85	258	118	75	43	71	332	183	156	27	53
29	2.55	166	174	40	134	61	263	198	163	35	38
30	3.12	240	256	78	178	68	354	195	195	0	45
Oct. 1	3.06	358	103	67	36	81	234	144	131	13	45
2	2.53	156	120	64	56	59	376	273	168	105	55
3	2.55	236	128	80	48	66	235	207	196	11	20
10	2.55	182	106	80	26	64	—	—	—	—	—
13	2.06	176	67	49	18	72	255	208	216	8	16
14	2.59	188	64	57	7	70	370	272	238	34	36
15	2.30	210	90	65	25	69	315	235	211	24	33
16	2.64	240	97	50	47	79	165	135	125	10	25
17	2.27	263	128	80	48	70	174	160	155	5	11
24	2.72	254	166	86	80	66	*363	307	100	207	73
22	2.57	224	121	118	3	47	263	235	215	20	18
23	3.03	312	148	97	51	69	237	194	161	33	32
27	2.03	120	68	38	30	68	249	233	215	18	14
28	2.75	386	111	85	26	78	333	210	200	10	40
29	2.79	162	94	65	29	61	228	206	199	7	13
30	6.61	196	117	68	49	65	—	—	—	—	—
31	5.01	58	104	38	66	35	—	—	—	—	—
Average	2.96	225	120	69	51	70	279	204	167	37	47

* Oct. 21st.

Table IV shows the average operation and analytical results for October when the Perth Amboy plant was operated without chemicals; and for November when only a small amount of lime to aid sludge conditioning was added to the sewage during a part of the month. Excepting 3 days when the suspended solids in the effluent exceeded

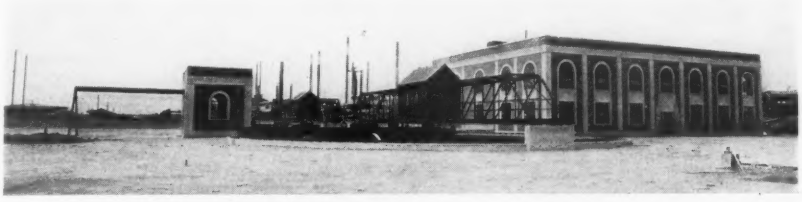

FIG. 1.—Perth Amboy Treatment Works.

90 p.p.m., there was relatively little variation in suspended solids discharged during the 2 months. The maximum flow treated in the clarifier was 6.29 m.g.d. on November 28th.

Chemicals were applied to the sewage from September 11 to 14 and September 20 to 28 (inclusive). The entire plant was by-passed from October 6 to 9 (inclusive) for the purpose of cleaning the wet well.

TABLE IV.—*Perth Amboy Operating and Analytical Results. Two Months* No Chemicals Except as Noted *

1935	Flow m.g.d.	Det. per Hrs.	Filter Rate/Gal./ Sq. Ft./Min.	Suspended Solids			5-Day B.O.D.		
				Inf.	Eff.	Pct. Rem.	Inf.	Eff.	Pct. Rem.
Oct.	2.79	3.4	0.76	200	59	71	264	186	30
Nov.	3.27	2.8	0.89	185	58	69	222	153	31
Dec.	3.33	2.6	0.93	225	68	70	262	181	31

* Average of 220 lb. lime per m.g. added to sewage from November 12th to 30th for preconditioning sludge.

All the sewage at Perth Amboy was handled in one clarifier, resulting in a detention period based on displacement time of about 3.0 hours and a filter rate of 0.85 gal. per sq. ft. per min. for the period of operation without chemicals. An average of 120 p.p.m. suspended solids reached the filter as indicated by samples taken under it. The filter removed 51 p.p.m. or 23 per cent of the suspended solids in the raw sewage. An average of 37 p.p.m. or 13.3 per cent of B.O.D. in the raw sewage was removed. During this same period an overall reduction of 70 per cent in suspended solids and 47 per cent in B.O.D. was obtained. The lower B.O.D. removals in October and November may be attributed to 4 or 5 ft. sludge accumulations in the clarifier.

Magnetite Filters Applied to Chemical Precipitation

Results at Dearborn over a period of four years and now for several months at Perth Amboy indicate the workability as well as efficiency of magnetite filters on chemically precipitated liquors for producing a clean looking effluent free from suspended solids.

Fig. 2.—Magnetite filter at Perth Amboy.

Data obtained at Coney Island compare results of tests on chemical precipitation carried out in two tanks operated in parallel; one equipped with a magnetite filter and the other not so equipped.

Summary of Dearborn Results

Table V shows past and recent results of operation at Dearborn on raw sewage alone, from data obtained in co-operation with, furnished or published by Mark B. Owen, Superintendent of the Department of Public Works and Engineering, and E. C. Miller, Engineer of Plant Operation of the City of Dearborn. Table VI shows the recent results by months.

Changes at the Dearborn Plant completed and put in operation early in 1935 consisted of provision for about 5 minute air mixing and 20 minute paddle flocculation and new lime and ferric chloride feeding machines. The use of paper was discontinued after the remodeling of the plant. Lime is added at the inlet and ferric chloride near the end of air mixing channel.

The Dearborn results reported are for raw sewage alone treated in one clarifier. The East Side sludge was kept separate by being stored in the other clarifier, from which it went directly to the vacuum filters. The supernatant from the sludge concentration tank was dis-

charged to the sewage clarifier. It is of interest that during the past 7 months one clarifier and magnetite filter was operating near its design capacity and that the B.O.D. of the raw sewage has increased in

TABLE V.—*Dearborn—Operating and Analytical Results—Raw Sewage Alone*

Date	Filter						Susp. Solids			5 Day B.O.D.		
	Flow M.G.D. Rate	Det. per Hrs.	Rate Gal./Sq. Ft./Min.	Chemicals Used Lb. per M.G.			Inf.	Eff.	Per Cent Rem.	Inf.	Eff.	Per Cent Rem.
				Lime	$FeCl_3$	Paper						
May 21 to July 19, 1932.....	1.11	3.6	0.51	245	235	212	212	20	91	112	38	66
Oct. 30 to Nov. 28, 1933.....	2.40	2.0	1.30	220	250	154	227	18	92	113	28	75
Nov. 1933 to April, 1934...	2.52	1.7	1.53	147	306	73	230	19	92	128	28	78
May 1 to Nov., 1935.....	2.78	1.5	1.48	256	307	—	297	25	92	175	43	76

strength. This is partly due to new tributary sewers recently connected to the plant. At current prices paid for chemicals, the Dearborn sewage is being treated at a chemical cost averaging about $5.40 per million gallons.

SUMMARY OF PERTH AMBOY CHEMICAL TREATMENT RESULTS

Table VII shows two months operation with chemicals at Perth Amboy. Data are from records by Louis P. Booz, Consulting Engineer and Mr. Frank A. Leahy, Superintendent supervising operation. All of the sewage reaching the plant is treated in one clarifier, which is

TABLE VI.—*Dearborn—Operating and Analytical Results—Raw Sewage Alone. May to November, 1935, inclusive*

Date	Flow m.g.d.	Det. Rec. Hrs.	Filt. Rate Gal./ Sq. Ft./ Min.	Chemicals			Suspended Solids			5-Day B.O.D.		
				Used per M.G.		Cost per M.G.	Inf.	Eff.	Pct. Rem.	Inf.	Eff.	Pct. Rem.
				Lime	$FeCl_3$							
May.....	3.87	1.10	2.06	152	256	$4.30	101	25	76	95	37	62
June.....	3.38	1.25	1.81	155	248	4.19	191	21	89	141	37	74
July.....	3.05	1.39	1.63	236	272	4.79	357	22	94	219	53	76
Aug.....	2.74	1.55	1.47	300	327	5.80	460	27	94	195	36	82
Sept.....	2.18	1.95	1.17	312	380	6.63	375	31	92	226	49	78
Oct.....	1.97	2.16	1.05	440	412	7.45	356	33	91	201	46	77
Nov.....	2.23	1.90	1.20	200	264	4.56	235	19	92	145	42	71
Average.....	2.78	1.53	1.48	256	307	$5.39	297	25	92	175	43	76

TABLE VII.—*Perth Amboy Operating and Analytical Results. Two Months Using Chemicals*

Date	Filter					Suspended Solids			5 Day B.O.D.		
	Flow M.G.D.	Det. per Hrs.	Rate Gal./Sq. Ft./Min.	Chemicals Used Lb. per M.G.		Inf.	Eff.	Per Cent Rem.	Inf.	Eff.	Per Cent Rem.
				Lime	$FeCl_3$						
July, 1935.....	2.56	3.7	0.70	643	291	215	21	90	242	86	65
Aug., 1935.....	2.92	3.2	0.79	675	214	264	35	87	271	116	55

running at about half design capacity. During September, 1935, operation without chemicals was started and the results are reported in another part of this paper. It is expected the chemicals will be used only during the summer months.

Ferric chloride is introduced in liquid form at the pump suction. Lime is added at the inlet of the flocculator. Mixing is effected by an air flocculator which, at present flows, has a detention period of approximately 30 minutes.

The Perth Amboy sewage is highly industrial; strength and character vary over a wide range. During a 24-hour period pH values from 2 to 9 have been observed. Lack of familiarity of adjustment of chemical feed for these sudden changes, erratic dosing and accumulation of sludge in the clarifier for a period of as long as 8 or 9 days have

TABLE VIII.—*Perth Amboy—Mechanical Filtration of Chemically Precipitated Sewage. Results of Operation in September, 1935, When Chemicals Used*

Date 1935 Sept.	Flow M.G.D.	Chemicals Used		Suspended Solids				5 Day B.O.D.			
		Lime	$FeCl_3$	Raw Sewage	Under Filter	Filtered Effluent	Per Cent Overall Reduction	Raw Sewage	Under Filter	Filtered Final Eff.	Per Cent Overall Reduction
1	2.78	504	234	750		28	96.3	532		92	82
2	2.67	525	195	372		37	90.0	400		115	71
3	4.89	350	175	490		37	92.4	341		84	75
4	5.40	315	127	158		12	92.4	109		59	44
5	5.99	268	136	188		30	84.0	149		83	43
11	3.35	598	196	130	82	48	63.0	166	112	97	42
12	3.27	600	195	172	54	24	86.0	169	83	75	55
13	3.35	620	240	274	52	17	93.8	202	100	91	55
21	2.85	605	252	340	—	35	90.0	462	—	149	68
22	2.52	635	256	116	74	22	80.0	225	119	133	41
23	2.58	709	382	184	61	22	88.0	324	134	137	56
24	2.46	660	276	320	130	28	91.3	392	139	129	42
25	2.80	645	339	400	134	14	96.5	402	120	114	72
26	2.70	640	285	224	172	20	91.0	222	220	144	35
27	2.81	580	263	242	—	25	89.7	244	—	122	50
	3.36	550	238	291	95	27	91.0	290	128	108	56

undoubtedly had a detrimental effect on the quality of effluent, consequently affecting the chemicals required. The cost of chemicals has averaged about $8.00 per M.G.

Table VIII shows the results of operation at Perth Amboy with chemicals during September, 1935. The detention period was 2.8 hours and the filter rate .91 gal. per sq. ft. per minute. An average of the days when samples were available above and below the filter shows a removal of about 70 p.p.m. suspended solids and 13 p.p.m. B.O.D. Because of the high chemical dose and long detention period, a minimum of work remained to be performed by the filter. Whereas the solids in the liquor below the filter varied from 52 to 172 p.p.m. the filtered effluent varied only between 14 and 48 p.p.m.

Chemical Treatment Tests—Coney Island

Table IX compares chemicals used and results obtained in the filter-equipped and plain tank at Coney Island. Data have been grouped

Table IX.—*Comparison of Chemicals Used and Suspended Solids Reduction Between Plain Sedimentation Tank and Filter Equipped Tank Parallel Operation Coney Island Tests (Data Grouped According to Chemicals Used and Detention Periods)*

Chem. Range Lb. per M.G.		Det. per Hrs.	Filter Rate Gal. Sq. Ft./Min.	Chemicals Used Lb. per M.G.		Suspended Solids		
				Lime	$FeCl_3$	Inf.	Eff.	Pct. Rem.
Lime 0–300	Settler	1.90		268	100	116	29	75
$FeCl_3$ 0–250	Filter	2.00	1.9	177	41	116	27	77
Lime 300–500	Settler	2.00	—	435	190	130	30	77
$FeCl_3$ 0–250	Filter	1.83	2.1	435	190	130	15	89
Lime 300–600	Settler	1.00	—	420	200	126	30	76
$FeCl_3$ 100–250	Filter	.97	1.9	390	200	126	18	83
Lime 300–600	Settler	1.98	—	517	288	124	23	82
$FeCl_3$ 250–400	Filter	1.98	1.9	344	172	124	13	90
Lime 300–600	Settler	1.00	—	627	270	125	15	88
$FeCl_3$ 250–400	Filter	.98	1.9	397	240	125	9	93
Lime 600 +	Settler	1.00	—	814	177	90	24	73
$FeCl_3$ 0–250	Filter	.98	1.9	683	177	90	15	83
Lime 600 +	Settler	2.02	—	655	201	102	30	71
$FeCl_3$ 0–250	Filter	1.91	1.9	655	201	102	22	78
Lime 600 +	Settler	1.99	—	1015	365	138	11	93
$FeCl_3$ 250–400	Filter	1.97	1.9	499	292	138	5	96
Lime 0–300	Settler	1.01	—	458	353	107	19	82
Chl. Copperas 250–400	Filter	0.99	1.9	400	350	107	13	88
Lime 0–300	Settler	2.00		417	388	122	20	84
Chl. Copperas 250–400	Filter	1.95	1.9	408	348	122	11	91

according to quantities of chemicals used and detention periods of one or two hours. Two tests were with chlorinated copperas. The filter rate was from 1.9 to 2.1 gal. per sq. ft. per minute. These results indicate the following:

1. The magnetite filter showed the greatest improvement in effluent over the plain tank, in shorter detention periods with low usage of equal amounts of chemicals.

2. Effluents equal to the plain settled were obtained with much less chemical usage by the filter-equipped tank.

3. Large dosage of chemicals and long settling periods resulted in only slight improvement by filtration.

4. Effluents of higher quality, with less chemicals and in shorter time were obtained after filtration than by sedimentation alone.

Summary Miscellaneous Chemical Tests—Coney Island

Results of other tests carried out, for which data are available but not included in this paper, are worthy of mention as follows:

Paper pulp was added in some of the tests, but no conclusions were reached as to the possible advantages or benefits to be derived.

Very good precipitation was obtained by iron salts at a pH of 4.5 adjusted by sulphuric acid. The practical use of this treatment is of course limited by effects on structures.

Pre-sedimentation followed by chemical coagulation and secondary settling, with sludge returned from the secondary to the primary tanks was tried in three tests; both with and without magnetite filters on the secondary tanks. No evidence of any advantages to be gained by pre-sedimentation or return of sludge for this type of sewage were present either from data or observation.

Activated Sludge Tests—North Side Plant Chicago

Tests with a 20 ft. diameter tank equipped with a 3 ft. wide filter at the North Side Sewage Treatment Works (reported This Journal, May, 1935) demonstrated the workability of a magnetite filter on settling-filtering activated sludge aeration tank mixed liquor.

Effluents of 4 to 5 p.p.m. B.O.D. were obtained at settling rates of 2,000 gal. per sq. ft. per 24 hours and filtering rates of 2 gal. per sq. ft. per min. Suspended solids and B.O.D. of 8 to 10 p.p.m. were obtained at settling and filtering rates increased by 50 per cent. Operations at higher settling rates were limited by the inability to concentrate the sludge. At filter rates of 6 for short periods, 5 for periods of a day and averaging 4 gal. per sq. ft. per min., the effluent contained about 15 p.p.m. suspended solids and B.O.D.

Data of operation on settling filtering liquor taken half-way down the aeration tank indicated possibilities of reducing the aeration period and air used when final sedimentation is followed by filtering. This particularly adopts itself to an overloaded plant in lieu of extension,

or as a protective device to counteract under-activation, poor settling or bulking sludge.

Trickling Filters

A 20 ft. diameter tank equipped with a 3 ft. wide magnetite filter has been loaned to the authorities at Atlanta, Ga. Tests with this tank have been conducted at the Intrenchment Creek Plant under the joint direction of Mr. Wm. A. Hansell, City Engineer, and Mr. M. T. Singleton, Consulting Engineer.

Fig. 3.—Magnetite filter at Goshen, Indiana.

The purpose of the test was to find a means of increasing the capacity of the overloaded trickling filters. The tank with the magnetite filter was placed following the old Imhoff tanks and ahead of the trickling filters. At first the Imhoff effluent was precipitated with chlorinated copperas alone or with lime, settled and filtered in the magnetite filter tank and applied to the trickling filters at a rate of 6 m.g.a.d. It was later found that unsettled raw sewage could be precipitated with less chemicals than was required by the effluents presettled in the Imhoff tanks.

In the course of these tests, the effluent from the magnetite filter was applied to the trickling filter at the same rate of 6 m.g.a.d. When no chemicals had been added at any point previous. Tests were also made on raw sewage treated with chemicals, settled in the Imhoff tanks, dosed on the trickling filters at 6 m.g.a.d. and strained through a small filter bed of magnetite in the laboratory.

As the results of tests, it has been concluded that for Atlanta conditions, automatic magnetite filters have their best application, following trickling filters dosed at high rates, for use as strainers on humus tanks which have only about 45 minutes detention instead of the usual 1½ hours. The Atlanta work is mentioned as part of the recent development work with the magnetite filter. It is expected that operating results and data will be available at an early date.

Summary of Removals by Magnetite Filter and Wash Water

Summaries of analytical and operating data have been included to furnish evidence of the work performed by the magnetite filters and settling characteristics of wash water returned to the tank influent as follows:

1. As indicated by samples taken just below the magnetite filter compared with the final filtered effluent.
2. By the solids actually trapped by the filter determined from samples of wash water.
3. Comparison of the difference in parts per million of total and volatile suspended solids and B.O.D. with total and volatile suspended solids in wash water.
4. Comparison of settleable solids in wash water with raw sewage.

Table X shows Coney Island suspended solids results of analysis of wash water, raw sewage and filtered effluent, for tests when no chemi-

Table X.—*Removals of Suspended Solids by Magnetite Filter—Coney Island Tests. Comparisons from Wash Water and Differences between Parallel Operation of Settler and Filter Tanks—No Chemicals Used. Suspended Solids Results in Parts per Million*

Date	Raw Sewage	Settled Effluent		Filtered Effluent Coney Island	Increase in Removal of Filter over Settler	Wash Water	Trapped by Filter Calculated
		Average Results	Actual Coney Island				
July 31	92	48		32		648	32
June 26	97	50		50		560	27
July 18	100	50	57	46	11	596	29
Test 11A	117	56	72	44	28		
Aug. 5	129	62		47		648	31
June 29	132	63		66		628	31
Feb. 8	136	65	98	52	46		
Aug. 2	138	66		41		510	23
July 17	139	67		32		760	36
July 19	142	68	59	40	19	616	29
July 23	144	69	90	48	42	670	32
June 24	144	69		58		464	20
Feb. 9	154	74	110	56	54		
Feb. 10	184	88	88	52	36		
July 26	184	88	76	32	44	532	23
July 24	200	96	106	44	62	572	23
July 12	258	108		77		488	19
Aug. 6	266	112		60		576	23
July 13	282	118		74		397	14
Aug. 1	300	126		44		628	25
	167	78	84	49	38	580	26

cals were used. Measured flow of wash water for the tabulated period averaged 5.1 per cent. The suspended solids trapped by the magnetite filter averaged 26 p.p.m. after applying correction for solids already in the liquor reaching the magnetite filter. For those days when parallel tests were available, the filter tank removed an average of 38 p.p.m. more suspended solids than the plain tank. This indicates that the improvement of the filter results over the plain settler was due to the following:

1. Solids actually trapped by the filter.
2. Because of the improved filter tank hydraulics by the distribution of effluent discharge through the large filter area as compared with a thin weir, a certain amount of solids that normally pass over a weir did not reach the filter.

The location of the filter, therefore, evidently improves the hydraulic efficiency of tanks for sedimentation in addition to its ability to remove a certain amount of the solids reaching it. Velocities approaching the filter are lower than velocities approaching the ordinary weir.

Table XI summarizes the average removals based on samples taken below and above the filter for plain sedimentation (no chemicals) at Coney Island and Perth Amboy; chemical treatment at Perth Amboy and activated sludge liquors at the North Side Plant, Chicago. The maximum and minimum shown refer to the solids reaching the filter. The B.O.D. removals shown for Perth Amboy are for those days when maximum or minimum suspended solids reached the filter. The data indicate removals by the magnetite filter, based on samples before and after filtering, of 7 to 152 p.p.m. suspended solids and 13 to 75 p.p.m. B.O.D. The averages for the various conditions indicated are self explanatory.

Table XII shows the total and volatile suspended solids, B.O.D. removed by the filter, the total and per cent volatile suspended solids contained in the wash water, and the per cent of the total sewage flow which was retained as wash water at Perth Amboy for the periods of operation with and without chemicals. The parts per million removed by the filter are differences between samples taken below and above the filter. The cleaner was operated intermittently until September 11, 1935, and then was set to operate continuously, with the wash-water return pump discharging its maximum capacity. When the full capacity of the clarifier will be reached in the future, the total quantity of wash water returned will be the same but the per cent of return will be decreased about half.

In non-chemical treatment an average of 49 p.p.m. suspended solids was removed by the filter of which 59 per cent was volatile. The B.O.D. removed by the filter was 29 p.p.m. The per cent wash water ranged from 1.6 to 8.6 and contained from 450 to 1960 p.p.m. suspended solids. The wash water contained 67 per cent volatile suspended solids.

In chemical treatment an average of 67 p.p.m. suspended solids

TABLE XI.—*Summary of Removals by Magnetite Filters from Samples Taken Before and After Filtering*

Approximate Dates 1935	Ret. per. Hrs.	Filter Rate Gal./ Sq.ft./ Min.	Suspended Solids				B.O.D.				
			Raw Sew.	Under Filt.	Filt. Eff.	p.p.m. Rem.	Raw Sew.	Under Filt.	Filt. Eff.	p.p.m. Rem.	Rem.
Coney Island—Plain Sedimentation—No Chemicals											
June 1–7	1.0	3.7	95	69	44	25					
June 1–7	1.8	4.0	108	74	51	23					
Max.	1.8		160	120	74	46					
Perth Amboy—Plain Sedimentation—No Chemicals											
September and October, 1935	3.2	0.85	240	120	71	49	285	174	145	29	Av.
	3.1	0.87	426	144	88	56	472	189	161	28	Max.
	3.4	0.79	138	88	56	32	164	144	118	26	Min.
Perth Amboy—With Chemicals											
September, 1935	3.5	0.79	238	97	21	76	274	131	118	13	Av.
	3.5	0.76	224	172	20	152	222	220	144	76	Max.
	2.9	0.95	140	82	62	20	171	112	90	22	Min.
North Side Plant, Chicago—Activated Liquors											
	Settling Rate Gal./ sq.ft. 24 hrs.										
Sept. 13, 1934 to Feb. 10, 1935	2328	3.0		34	10	24 Av.		(Full aeration)			
	2080	2.5		128	7	121 Max.					
	2450	5.4		18	11	7 Min.					
Jan. 1 to Feb. 10, 1935	1410	1.6		35	16	19 Av.		(Partial aeration)			
	1880	2.3		106	19	87 Max.					
	2050	2.6		51	14	34 Min.					

were removed, of which 37 p.p.m. or 55 per cent was volatile. The B.O.D. removed averaged only 13 p.p.m., on some of the days showing negative removals up to a maximum of 76 p.p.m. B.O.D. removed. The accuracy and technique of B.O.D. determination in chemical treatment is a subject undoubtedly requiring further investigation.

The performance of the magnetite filter at Perth Amboy was investigated by the Minneapolis-St. Paul Sanitary District under the direction of their Engineering Department, represented in the field by K. L. Mick, Chemist, under the general direction of Mr. C. C. Wilbur, Chief Engineer, and Mr. Geo. A. Schroepfer, Ass't Chief Engineer.

TABLE XII.—*Comparison Suspended Solids and B.O.D. Removals by Filter and Wash Water, Perth Amboy, New Jersey, With and Without Chemical Treatment*

Date	Susp. Solids Rem. by Filter—p.p.m.		B.O.D. Removed by Filter	Wash Water		
	Total	Volatile		Susp. Sol. p.p.m.	Pct. Vol.	Pct. of Sewage Flow
Plain Sedimentation—No Chemicals						
Sept. 7	91	73	49	800	68	5.1
8	32	24	26	1190	71	1.6
9	25	8	46	1960	67	1.6
10	45	22	18	1230	55	3.6
15	48	15	30	450	69	8.3
16	52	37	45			
17	56	34	28	744	68	7.1
18	46	33	− 8	558	69	8.6
19	43	15	27	574	70	7.6
Average	49	29	29	938	67	5.4
With Use of Chemicals						
Sept. 11	20	6	22	510	63	5.3
12	30	15	8	285	58	6.1
13	35	14	7	226	57	6.6
20	49	16	−11	302	68	7.2
22	52	32	−14	180	67	8.6
23	39	6	− 3	298	48	8.4
24	102	68	10	266	65	8 8
25	120	80	6	138	59	7.8
26	152	100	76	198	52	8.0
Average	67	37	13	267	60	7.4

SETTLEABILITY OF WASH WATER RETURN

Particles of solids which normally do not settle in the sedimentation tank after being trapped in the magnetite filter and returned as wash water are quite settleable. This has been demonstrated by total and settleable solids determinations made on wash-water samples from time to time.

Table XIII compares total and settleable suspended solids in raw sewage and wash water in non-chemical plain sedimentation tests at Coney Island. The settleable solids in raw sewage amounted to 58 per cent and in wash water 71 per cent of the suspended solids.

EVALUATION OF MECHANICALLY STRAINED EFFLUENTS

Mechanical straining of effluents places a new tool at the disposal of the sanitary engineer. How it shall be applied and used is his problem and not the subject of this paper. The data presented, however, indicate that the filter removes suspended solids not removed by the ordinary preliminary or final settling tank. This additional removal

TABLE XIII.—*Percentage of Settleable Solids in Raw Sewage and Filter Wash Water. Non-Chemical Plain Sedimentation Tests Coney Island*

Date	Filter Tank Influent			Wash Water		
	Total	Settleable	Per Cent Settleable	Total	Settleable	Per Cent Settleable
July 12	258	134	52	488	304	62
13	282	183	63	397	276	70
17	139	91	65	760	512	67
18	100	69	69	596	451	76
26	184	109	60	532	392	73
31	92	18	20	648	476	42
1	300	172	57	628	458	73
6	266	172	63	576	382	68
Average	203	118	58	578	410	71

should minimize to a great extent the possibility of sludge forming depositions, especially in sluggish or stagnant receiving bodies of water. Greater benefits are therefore to be derived from the filtration of effluents, when measured by the dilution waters required, than indicated merely by the per cent removal of B.O.D. alone. Some means are therefore required of evaluating an effluent of a definite B.O.D. content, which contains appreciable putrescible suspended solids, with one of similar B.O.D. content but containing a lesser amount of such solids.

CONCLUSIONS

The following conclusions may be drawn from the data on the magnetite filter:

1. The magnetite filter and cleaner is mechanically adaptable to filtering—(*a*) plain settled, (*b*) chemically treated sewages, (*c*) activated sludge aeration liquors and (*d*) trickling filter effluents.

2. Maximum filter rates up to 6 gal. per sq. ft. per min. and average continuous filter rates from 2 to 3 gal. per sq. ft. per min. have been demonstrated.

3. Positive greater removals of suspended solids, not removed by ordinary sedimentation, averaging 25 to 60 p.p.m. and maxima of over 150 p.p.m. have been obtained by the filters. The suspended solids removed are in direct ratio to the amount of solids reaching the filter.

4. Loss of head through the filter is not excessive, normally reaching a maximum of 3 inches of water.

5. The filter bed provides protective features acting as a safety valve to counteract irregularities in operation which result in non-uniform settling. The filter smooths out fluctuations and produces an effluent of greater uniformity.

6. By installing a magnetite filter on a sedimentation tank it is possible to reduce the size of the tank volume required, preceding it, and at the same time produce a better effluent than from ordinary sedimentation.

7. Provides uniformity of effluent with minimum of chemicals and makes possible considerable savings in chemicals to produce an equal or better effluent than tanks without filters.

8. For seasonal chemical treatment reduces the number of days during the year requiring chemical dosage.

9. Provides an automatic mechanical means of polishing up activated and trickling filter effluents. Effluents as low as 5 p.p.m. suspended solids and B.O.D. are possible.

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SEWAGE DISPOSAL PRACTICE IN CANADA*

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Methods adopted for the disposal of sewage in Canada are many, and operating difficulties are varied. Climatic conditions, stream flows, type of plant and other related factors all have a direct bearing on the experiences reported. In comparatively recent years many modern plants have been placed in service. Some of these have been operated by technically trained men, others by men with no previous training or knowledge in this work. Both types of operators have been faced with many problems, the solution of which has helped to advance the knowledge in this field.

Sewage disposal works are increasing in number in all provinces of the Dominion. At present there are 71 municipal plants in Ontario, of which 31 are of the activated-sludge type. Many are for partial treatment only, while some are of a type now regarded as obsolete. This number of treatment works may seem few when compared with the number of urban centres, but it is well to remember that sewerage systems seldom make the rapid progress of waterworks, and also that many municipalities situated on large bodies of water have for years discharged raw sewage into such bodies of water.

Operating Difficulties.—The chief operating difficulties have occurred at plants of the activated-sludge type. This is to be expected in view of the sensitiveness of the method, and since it is a complete treatment process, in which efficient results are expected. In recent years, with increasing knowledge of the intricacies of the process, methods have been devised to correct temporary upsets. Ontario plants have been influenced by such factors as the presence of septic conditions in the activated sludge, bulking of the sludge, injurious trade wastes, variations in sludge content, variations in the rate of sewage flow, inadequate capacity of the plant, depleted finances, weather and many other matters of a similar nature.

Septic Conditions.—Probably one of the most frequently encountered difficulties in operation of activated-sludge plants in Ontario has been septic sludge in the aeration tanks. Its grayish or black appearance serves as a warning to the operator that the process is not functioning properly. In some plants the sludge has taken the appearance of digested solids from an imhoff tank, or from a separate digestion unit. Apart from the interference with the condition of the effluent, objectionable odors are developed, and if the plant is unfavorably located complaints may be expected to follow.

As to the causes of septic conditions, there may be several. In some cases the fault unquestionably lies with the plant itself; in others the

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method of operation may well be open to question. An overloaded plant may be expected to react by turning septic. An example of this was found at the Spring Street Works at Kitchener, where prior to enlargement the plant was continually in a septic state. Increasing the air supply, chemical treatment and similar measures failed to bring about any lasting effects. The concentrated nature of the sewage reaching the plant left no alternative to an extension. Since this has been completed little difficulty has been experienced with black sludge.

Plants with an inadequate supply of air may anticipate similar experiences with septic sludge, particularly in the warmer weather. Attempts to conserve power costs by avoiding peak loads or by the operation of more than a minimum number of compressors are fraught with danger.

The unskilled or inefficient operator may readily throw out of adjustment a well designed plant. The good results, on the other hand, which can be accomplished by a skilled operator at a none too efficient plant is convincing proof of the part played by the person in charge. There are many ways in which operators may bring about septic action in a plant. Some of those which have been noticed at different places include unnecessary reduction in air supply, incorrect control of sludge content, delay in the return of sludge from the settling tanks, accumulation of sludge in grit chambers, improper distribution of digested sludge overflow, etc.

Too much emphasis cannot be placed on careful supervision of the plant. The control of a highly sensitive and important process is no responsibility for a man who is either disinterested, indolent, lacking in observation or who is not sufficiently interested to acquire knowledge of the factors involved.

The question for the engineer and the plant superintendent is "How is this septic condition to be prevented or corrected?" Provided with a plant of sufficient capacity and a normal, uniform sewage, there are many measures available. Increased air delivery has proven to be a distinct aid in the correction of septicity. Chloride of lime has likewise been a very valuable corrective agency. Any plant in which septicity may develop should have a supply of chloride of lime on hand at all times. These two measures are probably the most valuable aids against septic action the operator has for emergency use.

Bulking of Sludge.—Bulking of sludge in activated-sludge plants is a frequent trouble maker. A very good effluent may have been produced, but suddenly the sludge refuses to settle and is carried over with the effluent; or the operator note that the volume of sludge has increased tremendously. The settling test for the sludge in the aeration tank is not then a true indicator of the quantity of active sludge. To what extent thread-like, filamentous organisms appear in our activated-sludge plants is not well known. This condition has developed at least in the plants at London and Kitchener. The organism in these two cases was identified as *actinomyces*. It interfered with settling, and

the sludge became a stringy mass which would hang from screens, bars, or other projections.

What is the cause of this bulking phenomenon? Opinions on this appear to lack unanimity. Different reasons have been ascribed, varying from excessive concentration of organic matter to the presence of excess carbohydrates. What effect has a deficiency or an excess amount of oxygen on the sludge? No specific cause for the filamentous growths at London and Kitchener seemed apparent. In one case they disappeared without any change in the operation, while in the other chloride of lime quickly destroyed them. Experience with respect to bulking in the Canadian plants should tend to shed some light on the cause of this phenomenon. More complete record of observations at these times should be made available.

Trade Wastes.—The interference of certain trade wastes with activated-sludge plants, as well as with other types of treatment has been noted at different places. This interference has taken the form of direct overloading as well as a toxic or similar effect upon the process. The policy of permitting all kinds of concentrated wastes to go untreated into the public sewers is open to criticism. In this country more than others, there has been much latitude given to manufacturers. Probably in the larger centres this is of less significance due to dilution of the wastes. In the smaller centres it is not infrequent to find such wastes making up a major portion of the flow reaching the works. In one plant the solids from a tannery caused a tremendous load on the sludge beds, another designed to treat 1.0 million gallons per day, was receiving buttermilk equivalent to about 300,000 to 400,000 gallons of sewage per day. In another, distillery wastes having a hydrogen-ion concentration of 3.5 interfered with the operation of a filter, because of the acidity and the amount of fine solids carried. Similar conditions are encountered in other places. It would seem only fair that such concentrated wastes should be given some preliminary treatment before they are discharged to the public sewers. The added cost for treatment of these wastes by public funds cannot always be justified.

Variations in Sludge Content.—The amount of sludge carried in the aeration tanks of the different plants varies within wide ranges. Some are able to get best results with less than 10 per cent, based on a half-hour settling test, while some carry as much as 40 per cent. In warm weather the retention of an excess of sludge makes the prevention of septic conditions difficult. Where sludge disposal facilities are adequate there is but little reason for carrying a high sludge content. Plant operators would do well to determine the figure which gives best results under different conditions.

Variations in Sewage Flow.—Extreme variation in the flow of sewage reaching disposal works is not conducive to best results. Overloading may occur, and settlement of solids be interfered with, both because of the high flows and the strength of the sewage at certain periods. This difficulty is found in a number of plants, and may be due either to normal variations in the sanitary flow; to intermittent pump-

ing; or to excessive storm water. Periodic pumping of sewage at high rates is particularly noticeable in the smaller works, where it tends to carry the liquid through the plant at a rate in excess of the designed capacity. Seldom does it reach the point where an excessive quantity of activated sludge is carried into the effluent. This latter condition is, however, experienced not infrequently in combined sewers when heavy storms occur. While it may be an effective remedy for the removal of surplus sludge, it is not a procedure to be recommended.

Wide variations in sewage flow raise the question of the advisability of constructing balancing tanks. There are situations where such a procedure would be valuable not only in smoothing out the flow curve, but also in better mixing of the dilute and concentrated sewages.

Inadequate Capacities.—Inadequate capacities in sewage treatment works may bring about conditions over which the operator can have but little control. All too frequently a plant designed for a specific flow has long since reached its upper limit. Expenditure of money for sewage disposal seldom has much public appeal, and it is even more difficult to obtain funds for the extension than for the initial works. As a result of this the engineer can scarcely be criticized if he provides at the beginning ample capacity for a number of years. A better appreciation of the need for adequate treatment of sewage would lessen the problem of the engineer and the operator.

Effects of the Weather.—The weatherman may have a voice in the operation of plants, sometimes very noticeably and at other times in a less direct way. Hot weather and high sludge contents do not make a good combination. Septic sewage, brought about by warm weather, as it reaches the plant is not desirable for best efficiency, and the operator must be ever alert when these conditions are present. Cold weather seems to have very little influence on the Ontario plants other than to create physical and mechanical difficulties for the operator. The freezing of air valves, the formation of sleet and ice on tractor rails and similar problems add to the concern of the man in charge.

Training of Operating Personnel.—It is only in the larger disposal works of this Province that technically trained personnel have been in charge. For the most part the operators are those who have had no previous training in plant operation. Some of these become very proficient, especially if they are ambitious enough to inquire after knowledge. Others, finding that they have little opportunity to see any plant other than their own, become discouraged. It is unfortunate that these men are not given greater means for acquiring knowledge. Courses of instruction would be most useful. Likewise an occasional visit by the operator to other plants would be most helpful, and would well repay the municipality concerned.

Final Effluents.—The effluent produced from the modern sewage disposal plant is a problem of much concern, and of course constitutes the basis for determining the efficiency of the works. What standard should we strive for, and what latitude may be allowed for local conditions? Variations may be expected both in the same plant and at

different plants. All these conditions may be somewhat confusing to the layman, and the operator is not always clear as to what is expected of him.

Whatever standard may be considered as constituting a high class effluent, it goes without argument that the effluent should be such that local conditions will be satisfied. Moreover, it is unnecessary and uneconomical to carry treatment beyond a point which the condition of the receiving water makes necessary.

The same standard for the effluent may not be required at all times of the year, and there is a growing tendency to take advantage of this variation. This requirement is particularly true in Canada where climatic conditions vary so greatly. For many streams, treatment of sewage has been required only because of increased biological activity during the hot weather, at which time the discharge of raw or partly treated sewage would create an offensive state in the water. In the winter months these conditions do not hold and an effluent of lower quality might suffice. Certain types of treatment lend themselves to this practice. There is, however, a tendency, where such a process as the activated-sludge is used, to fail to appreciate the need for effective operation during the summer if any lowering of standard is permitted during the winter. As a matter of policy, therefore, any change in the standard may be beset with difficulties.

For obvious reasons it has not been considered desirable to set up hard and fast standards for sewage treatment in Canada. Conditions vary so much that every case can best be considered on its own merit, and a standard so fixed as will be sufficient.

Definite standards for final effluents have been recognized elsewhere. The figure of the Ministry of Health of England of 30 p.p.m. suspended solids and 20 p.p.m. biochemical oxygen demand have been accepted in many places. River Boards in England such as the West Riding of Yorkshire Rivers Board have also adopted standards for quality, designed to meet specific needs over a limited area, and where conditions might be regarded as somewhat uniform. Standards for the degree of treatment before discharge into the Great Lakes also call for mention, and while no fixed standard for the effluent has been specified the degree of treatment to be provided has been incorporated in the standards and in the agreements between contiguous states.

The many disposal plants now operating in Canada offer a comparison between these effluents and the standards set elsewhere. It is observed that in some plants there is no difficulty in meeting the British Standards, and even in producing better results. In others the results obtained appear to be influenced very largely by concentration of the sewage reaching the plant, and by the working capacity of the plant. Some plants, appearing to be working effectively, fail to produce effluents of this standard. In many cases such a high standard is uncalled for. Frequent examination of the effluents to determine the quality is not always feasible for the small plants where no laboratory facilities are available. The operator must therefore rely on simpler

tests. Observation on the condition of the sludge, the clarity of the effluent, combined with the test for relative stability have proven of great assistance in these cases.

The standards for effluents which have been set up are largely based on physical and chemical examinations. Extensive work on bacteriological tests has not been generally carried out, yet there are situations where this becomes a prominent feature. This is especially true where water supplies are involved.

Sludge Disposal.—Of all the problems associated with sewage treatment none has received more attention in recent years than sludge disposal. New methods are being studied continually and every effort made to reach the ideal solution. The choice of methods employed has been influenced by the size of the works, and by the time of their construction. No great difficulties were involved in the older plants, where the sludge was discharged in a fairly inoffensive condition and could be dried readily on open beds. It was not until the advent of the activated-sludge system and more recent methods that the sludge problem became really acute.

A survey of the activated-sludge plants of Ontario shows that out of a total of 31 there are:

2—with sludge digestion and open drying beds
11—with sludge digestion and glass covered drying beds
2—with sludge dewatering equipment consisting of a vacuum filter
14—with open sand drying of raw sludge
2—with covered sand drying of raw sludge.

To-day a number of alternatives are available for the engineer faced with the problem of sludge disposal. These include sand bed drying, digestion, vacuum filtration, and dewatering by centrifugal action. The latter two may or may not be followed by incineration. Events are moving rapidly in this field, but when a standardized method will be recognized is difficult to predict. The size of the plant will probably continue to dictate the choice of method.

The Ontario plants have given some interesting results in sludge disposal, some of which are favorable and others quite the contrary. Digestion has been utilized in several plants, and while difficulties have been met it has been reasonably satisfactory. Smaller works have for the most part used this procedure. The condition of the overflow water must be carefully controlled.

There is probably a greater variation in the results on sludge drying than on digestion. Some have obtained excellent results while others find much difficulty. In the former group the city of Kitchener plant is conspicuous. Rapid drying of the digested sludge has always been obtained here with ease. It is sometimes difficult to appreciate the reason for these variations in sludge drying. At the Brampton plant the presence of certain trade wastes seemed to have a most injurious effect on the rate of drying. When these were excluded the difficulty

vanished. It would seem that there is yet an opportunity for studying the causes for these differences.

The drying of large quantities of raw sludge on open sand beds is not generally practiced. The cities of Stratford and Guelph have, however, met this problem particularly well, considering the circumstances. At these plants the sludge is applied in thin layers with the purpose of rapid drying, before odors can spread. While much labor is required, this practice has served very well as a temporary expedient.

Only two plants for mechanical dewatering of sludge are in operation in this Province. The experience obtained at these and others has shown this to be a feasible method. The most recent equipment to be marketed for this purpose is the centrifuge. Some experience has been had in Europe with somewhat similar devices. The chief advantage claimed is the dryness of the final sludge cake. No plants for the incineration of sludge on a large scale are operating in Ontario, but much work of a developmental nature has been carried on elsewhere.

CHEMICAL TREATMENT OF SEWAGE AT TWO WESTERN PLANTS *

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A review of operating results from sewage disposal plants which utilize chemical precipitation is of necessity a review of the literature on the subject, since the number of plant-size installations now in service is far too small to warrant general conclusions to be drawn.

My personal reaction to the recent articles on chemical precipitation is fairly well outlined by Mr. Kipling; in the last stanza of his poem "In the Neolithic Age," he says,

> "Here's my wisdom for your use
> As I learned it when the Moose
> And the Red Deer roared where
> Paris roars tonight
> There are nine and sixty ways
> of constructing tribal lays
> And every single one of them is
> right."

More or less intimate contact with two plant-size installations during the past year has convinced me that the efficiency and economy of chemical treatment are dependent on so many individual local considerations that general statements and conclusions are dangerous. Operating records which show excellent results at one plant may be quite accurate, but the duplication of these results at another plant, under another set of operating conditions, is not always possible.

At the present time, a number of important obstacles stand in the way of a fair valuation of chemical precipitation as a sewage treatment method. Among these are:

1. Lack of authentic operating data from plant size installations.
2. Lack of easily applied and reliable tests for plant efficiency.
3. Many of the existing installations use chemicals intermittently or at varying rates of dosage and representative operating costs are hard to determine.

There are other obstacles, but it is patent that until complete operating records for each of the numerous systems of chemical treatment are available for a period of at least a year in a number of installations, it will be impossible to predict results in individual instances with any great degree of accuracy.

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The results of B.O.D. determinations on chemically treated effluents are quite erratic as has been noted by a number of investigators and facilities for making routine solids and nitrogen determinations are not available at many of the smaller installations now in operation.

In view of the foregoing facts and since the status of chemical precipitation has been quite fully canvassed in the report of the Committee on Sewage Disposal (THIS JOURNAL, **7**, 997, Nov., 1935), which report is being submitted at this meeting, it seems rather futile to attempt another general review at this time, therefore the remainder of this paper will be devoted to results obtained at two plants where the opportunity of personal observation was presented. These results cover short periods of time, and are subject to all of the objections noted above, but are presented with the thought that they will at least indicate some of the features of chemical precipitation which need further study.

YORK, NEBRASKA

The plant at York, Nebraska, is equipped for primary settling, chemical mixing or flocculation and final settling. Sludge from the secondary tank is returned to the raw sewage pump sump for re-treatment and that from the primary tank is pumped to a digestion tank. The chemicals used are hydrated lime and ferric chloride and the latter is made at the plant by the Scott-Darcey process from chlorine water and crushed tin cans. The plant has a nominal capacity of 0.7 m.g.d. but to date the normal sewage flow has been less than half this amount. Operation was started in October, 1934. The use of chemicals has been limited to the period between 7:30 A.M. and 5:00 P.M. and the dosage during the periods of use has averaged 120 pounds of ferric chloride and 180 pounds of lime per million gallons. The detention periods in the various tanks are as follows:

	Design Basis	Actual Flow
Primary tank	1.5 hr.	4.3 hr.
Mixing tank	40 min.	1.9 hr.
Secondary tank	2.0 hr.	5.7 hr.

The conditions in the receiving stream have caused no complaint since the plant has been in operation, in spite of the fact that the natural flow of the stream was practically nil until April, 1934. The effluent at the plant outlet is inoffensive, and practically free from settleable solids, but is quite cloudy for the greater part of the time. The relative stability averages about 30 per cent.

Operating Results.—During July, 1935, a series of tests, covering seven complete days, was run by Mr. R. C. Mertz, of the Chain-Belt Company.

The results follow:

OPERATING RESULTS AT YORK, NEBRASKA

Determinations Made on 24-hour Composited Samples

	Sunday, July 14, 1935	Monday, July 8, 1935	Tuesday, July 23, 1935	Wednesday, July 10, 1935	Thursday, July 11, 1935	Friday, July 26, 1935	Saturday, July 20, 1935	Average
Sewage flow M.G.C.	.1869	.2462	.2641	.2421	.2650	.2472	.2357	.2410
Ph raw sewage	7.4	—	7.6	7.3	6.8	—	7.5	—
Chlorine used, pounds	37	38	29	35	46	24	31	34.3
Chlorine used, pounds per M.G.	198	154	110	145	173	100	108	141.0
Equivalent $FeCl_3$, pounds per M.G.	264	205	147	193	230	133	155	188.0
Lime used, pounds	50	50	50	25	25	50	25	39.3
Lime used, pounds per M.G.	269	206	189	103	94.5	202	88	164.0
B.O.D. raw sewage	—	—	161	129	—	205	235	182.5
B.O.D. plant effluent	—	—	56	53	—	75	59	60.5
B.O.D. per cent reduction	—	—	65.0	59	—	63.4	75.0	66.7
Suspended solids raw	312	364	338	192	236	308	262	287.4
Suspended solids plant effluent	48	100	40	28	72	46	52	55.1
Per cent reduction	84.6	72.4	88.2	85.4	69.4	85	81.0	81.7
Ph plant effluent	7.6	7.0	7.6	7.4	7.4	—	7.4	—
Dissolved oxygen raw sewage	3.9	2.6	4.7	3.4	3.4	4.0	2.5	3.5
Dissolved oxygen plant effluent	6.1	4.7	5.8	6.0	4.9	6.0	5.8	5.6
Oxygen consumed raw sewage	—	—	43	53	—	—	51	47.0
Oxygen consumed plant effluent	—	—	28	—	—	—	30	29.0
Oxygen consumed per cent reduction	—	—	35	—	—	—	41	38.0
Results from Experimental Filter								
Suspended solids plant effluent	48	100	40	28	72	46	52	55.1
Suspended solids filter effluent	26	8	14	16	8	16	8	13.7
Reduction by filter, per cent	7.2	25.2	7.7	4.1	27.1	9.7	17.0	14.4
Overall reduction, per cent	91.6	97.8	96	91.6	96.6	94.8	97.0	95.2
B.O.D. plant effluent	—	—	56	53	—	—	59	60.5
B.O.D. filter effluent	—	—	61	53	—	—	73	62.0
Oxygen consumed plant effluent	—	—	28	—	—	—	30	29
Oxygen consumed filter effluent	—	—	26	—	—	—	29	27.5
Dissolved oxygen filter effluent	6.9	3.7	4.9	4.6	5.7	6.7	4.6	5.3

The results shown above, indicate something between primary and complete (biological) treatment. The cost for chemicals for this treatment was as follows, per million gallons:

141 pounds Chlorine	@	$0.10	$14.10
164 pounds Lime	@	0.006	.98
Total			$15.08

It will be noted that with chlorine at $0.03 per pound, as would be possible if ton containers were used, the foregoing total would be $5.21.

Tests were run on an experimental filter formed of 6 inches of sand (effective size 0.45 mm.) supported on a 12-inch bed of graded gravel and dosed with plant effluent at a rate of 4 gallons per sq. ft. per minute. The results are given in the foregoing table.

The removal of suspended solids was quite satisfactory but the colloidal matter and color were not removed to the extent expected. It is also rather surprising that the removal of B.O.D. and oxygen consumed was apparently almost nil in spite of the removal of approximately 42 p.p.m. of suspended solids. The increase in dissolved oxygen in the settling tanks was rather unexpected, but this was probably due to surface aeration in the flocculator. During these tests, the effluent was pumped to the filter by a centrifugal pump, and it is probable that most of the floc was broken up in transit. The filter is now fed by gravity and further tests are to be run.

BOULDER, COLORADO

The plant at Boulder consists of a plain settling tank, of the center feed and peripheral overflow type. Provision has been made for feed-

ing chlorinated copperas and lime into the influent channel about 150 feet above the tank inlet to provide a short mixing period.

The sewage is quite dilute and ranges from 250 gallons per capita per day in winter, to peaks of nearly 400 gallons during the irrigation season. The tank affords a detention period of two hours at flows of 5.6 m.g.d. Chemicals have been used intermittently since the plant was put into operation in October, 1934. No chemicals have been used since June, 1935, except for a short test period in September, and chemicals have never been used during the night hours.

The operating costs for the first nine months of operation were as follows:

Operating Cost—Boulder Disposal Works

1934–35	Labor	Chemicals	Power	Supplies	Maintenance	Total	Per Million Gallons
Oct.	$ 45.60	—	—	$ 8.00	—	$ 53.60	$ 70.00
Nov.	312.80	$ 95.44	—	95.18	—	503.42	60.00
Dec.	309.40	169.36	$ 28.56	191.07	—	698.39	62.00
Jan.	429.20	131.19	29.05	80.54	$24.02	694.00	62.00
Feb.	121.50	38.90	31.78	17.60	16.98	226.76	56.00
Mar.	62.50	24.60	28.28	1.05	9.62	126.05	62.00
Apr.	60.00	89.94	24.52	—	—	174.46	60.00
May	89.50	109.19	30.16	.80	1.50	230.15	85.00
June	63.50	41.10	30.90	3.04	28.85	167.39	112.00
Total*	$493.00	$699.72	$203.25†	$397.28	$80.97	$2,874.22	$629.00

* Includes $872.90 for attendance required for temporary coal fired boiler previous to start of gas production.

† Includes $192.52 for coal and temporary boiler installation.

As noted above, a total of $1,065.42 is not chargeable to plant operation directly since the auxiliary boiler was not used after gas production started; the approximate total cost of plant operation was as follows:

Fixed charges—7½% of $53,000 for 9 months	$2,982.00
Operating cost less auxiliary boiler expense	1,788.80
Total cost	$4,770.80

The total cost per million gallons of sewage treated was $7.58, of which $4.74 was fixed charges and $2.84 operation. The total cost per capita annually (prorated from the nine months record) was approximately $0.53.

Operating Results.—Routine records of plant efficiency have not been kept but a study covering six days was made in September, 1935, with results as follows:

For the first three days of this test, 140 pounds of chlorinated copperas and 75 pounds of hydrated lime were used, per million gallons, during the period from 8 A.M. to 6 P.M.

These tests indicate little advantage from the use of chemicals but are clouded somewhat by the fact that the sewage flow, which averaged about 4 m.g.d., showed a variation of less than 20 per cent between

SUSPENDED SOLIDS
PARTS PER MILLION
With Chemicals

Day	Raw Sewage	Plant Effluent	Per Cent Reduction
1st	64	29	54.7
2nd	39	17	56.4
3rd	70	32	54.3
Total	173	78	
Ave.	57.7	26.0	54.9
Without Chemicals			
4th	32	13	59.4
5th	83	48	42.2
6th	59	27	54.0
Total	174	88	
Ave.	58	29.3	49.5

maximum and minimum rates, and the night flow was extremely dilute.

The suspended solids from the samples of chemically treated sewage contained about 5 per cent more volatile matter than those from the settled sewage, and this fact coupled with the fact that samples of creek water taken about one-half mile below the plant outlet have consistently shown relative stabilities of 80 per cent or more at times when the effluent was diluted by less than twice its volume of creek water, indicates that the full value of chemical treatment is not reflected in the foregoing results. However, it is obvious that the use of chemicals at this particular plant is justified only in critical periods.

The operation of these plants has raised a number of questions which are worthy of mention.

In the first place, the effect of the effluent on the receiving streams has been in both cases far better than the results of the tests would indicate, and this raises the question as to whether or not the chemical treatment has done something toward the reduction of the *rate* at which the oxygen demand of the effluent is exerted. The relatively high stabilities in the receiving streams would indicate that it has this effect, but supporting data is badly needed.

Visual examination of the chemically treated effluents invariably show the presence of flocculent material, and the advisability of filtration for such effluents is naturally suggested. The amount of experimental work on the rapid mechanical filtration, is entirely inadequate to form a basis for general conclusions, but it does show favorable indications of further development along this line.

It would seem that chemical treatment, in general, should be viewed in the light of a very promising method of disposal which is very definitely in the development stage.

Industrial Wastes

THE TREATMENT OF INDUSTRIAL WASTES IN CONNECTION WITH DOMESTIC SEWAGE *

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Industrial wastes present numerous problems in connection with municipal sewage treatment and abatement of waterways pollution. There are many considerations involved in obtaining the most satisfactory and economical solutions for these industrial waste problems. Such considerations include the administrative or legal, financial and technical aspects of each situation, none of which can be safely overlooked. Accordingly it is the purpose of this paper to discuss briefly some of these major considerations, and to describe certain developments in Wisconsin in connection with the treatment of several kinds of industrial wastes along with domestic sewage.

The policy originally followed by most manufacturers was to dump liquid wastes into the nearest watercourse as the most convenient method of disposal. Where municipal sewers were available and of sufficient capacity, trade wastes were often discharged into them untreated, with little or no protest. The public had not become aware of the harmful effects of unrestricted pollution of the natural watercourses.

The general outlook has changed. With the growing appreciation of the value of clean streams and the maintenance of proper sanitary conditions, there is an increasing insistence that sewage and wastes from industry be disposed of safely and inoffensively. Initial efforts to secure proper solutions for industrial waste problems generally met with considerable opposition. Much of the trouble encountered in accomplishing desired results, it is believed, has been due to a lack of a clear understanding on the part of the public and industrial plant officials as to just where responsibilities begin and end in these sewage and waste treatment situations. Nearly every industrial community has this common problem. There is always the question that must be faced of whether (1) Industry should independently take care of its problem or (2) A municipality should undertake as a community responsibility to treat or modify industrial wastes produced within the corporate limits so that they may be satisfactorily disposed of along with the domestic sewage, or (3) Industry and the municipality should jointly develop a sewage and waste disposal program.

According to information obtained from various state sanitary engineers there is no uniformity of policy with respect to admissibility

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of various trade wastes to public sewerage systems. Where any legal requirements have been established, they have usually been in the form of authorization permitting some designated agency to specify conditions under which use can be made of a sewerage system. In general there seems to be a tendency to extend the use of public sewerage facilities to manufacturers producing liquid wastes of a pollutional nature provided these wastes do not detrimentally affect sewerage structures or materially interfere with their operation. Probably because of a lack of information regarding limiting amounts and strength of wastes of certain types that may be satisfactorily taken care of in conjunction with ordinary domestic sewage through various kinds of modern municipal sewerage systems, there has never been established any generally accepted classification of industrial wastes from the point of view of amenability to treatment and disposal through public sewerage systems.

It is probable, however, that this situation will be changed with the present trend towards placing sewerage systems on a utility basis and establishing sewerage service charges dependent on the volume or character, or both, of sewage handled. This plan contemplates that those who benefit by sewerage service should pay a price commensurate with the service received, based on the fair average cost of rendering that class of service.

Some are of the opinion that trade wastes should be excluded from public sewerage systems in all cases where they vary appreciably from the character of domestic sewage or are very large in volume. In these cases it is the intention that the manufacturer be called upon to independently take care of his trade waste disposal problem. This may prove very difficult or practically impossible in some situations, and would sometimes entail an unwarranted financial burden. Also as a taxpayer in the community, industry is entitled to sewerage facilities. Such facilities have frequently been offered as an inducement to industry to locate in a municipality; the success of the former often constituting an important factor in the economic welfare of the latter. On the other hand a municipality cannot be expected to take care of wastes that rapidly deteriorate or render partially or completely ineffective sewerage works representing a large public investment. Accordingly to best arrive at an answer to the question of admissibility of trade wastes to public sewerage systems there should be a cooperative study of problems involved by officials of both the municipality and industry.

Solving Industrial Waste Problems

In making such a study the first step is usually to ascertain whether wastes may be advantageously utilized either in the manufacturing process or as valuable by-products. Possibly the wastes may be sufficiently reduced in volume or strength by minor changes in operating methods so as to render them unobjectionable when mixed with the domestic sewage. It may be found, however, that facilities need to be

installed at industrial establishments for equalizing flows or for providing preliminary treatment before the wastes can be satisfactorily handled with the municipal sewage. The services of consulting engineers, chemists and others experienced in dealing with sewage and trade wastes problems will generally prove very helpful in arriving with minimum delay at the most effective and economical procedure to be followed in any given situation.

Reclaiming of wastes, particularly if accomplished with a substantial profit over operating expenses, unquestionably is the most attractive procedure from industry's point of view. While this procedure is only feasible at present with relatively few kinds of wastes, experience of the pulp and paper industry has definitely shown that considerable savings accrue to the installation of saveall or whitewater recirculation systems in many cases. Results of mill surveys indicate the practicability of keeping fiber losses under 1 per cent and volumes of waste below 20,000 gallons per ton of product.[1] Progress has been made in recovering proteins from meat-packing plant wastes, cattle food from malt house wastes and distillery slop, casein plastic base from milk waste, and other valuable by-products from pollutional wastes discharged by a number of industries. Improved evaporating and drying equipment for producing powdered whey should tend to eliminate on a profitable basis the difficulties experienced in treating this strong milk plant waste at sewage disposal plants. By carrying waste utilization to its economic limits, the need for further treatment of effluents from some industries before discharge into public sewerage systems or watercourses may be eliminated or greatly minimized. The general policy in solving such problems, therefore, should be (1) reprocessing and salvaging of the wastes to the greatest possible degree, and (2) if difficulties are still encountered, installation of any effective and practical method available or capable of being developed to provide satisfactory preliminary treatment for the wastes.

Methods of Treatment

In those cases where recovery processes are not practical, a variety of methods of industrial waste treatment have been devised. Some of these methods are provided to serve as complete treatment for the wastes while others are intended only to modify the wastes in such manner as to permit effective treatment along with domestic sewage. Many industrial wastes contain substances which frequently interrupt or prevent bacterial action, materially interfering with the bio-chemical waste disposal processes usually afforded by municipal sewage treatment works. In addition, the flow and composition of many industrial wastes vary widely, thereby offering a major problem both in the design of sewage treatment works and in their subsequent operation.

Tannery Wastes

A problem was encountered in a Wisconsin municipality where tannery wastes are now being treated in clarifiers at the city disposal plant. (Figure 1.) The minimum hourly flow of tannery wastes was

Fig. 1.—Municipal sewage treatment works equipped with clarifier units for tannery wastes, which are conveyed to the plant by separate pipe line. The tannery sludge is discharged into lagoons at present, as shown in the foreground, but tests are being conducted to determine the feasibility of digestion of the tannery solids with the sewage sludge. It is contemplated that the sludge will eventually be dewatered on rotary filters prior to incineration or final disposal on nearby farms.

determined to be about one-third of the maximum hourly flow. The total daily quantity of waste was approximately the same as that for the city sewage at the time studies were conducted; but the discharge from the tannery occurred within a 12-hour period as compared with the sewage discharge over 24 hours. The physical and chemical characteristics of the wastes fluctuated appreciably. Accordingly, it has been necessary to provide suitable capacities in the tannery waste sump, pumping facilities and clarifiers to equalize flows and to secure fairly uniform removal of solids.

Until recently the new tannery waste treatment system has been operated separately from the municipal sewage disposal system, the clarified effluents not mixing until they enter the outfall sewer. Tannery solids have been disposed of entirely in lagoons, as shown in Figure 1, and sewage solids alone have been digested at the municipal plant.

Studies previously conducted by Elder * having indicated that up to 40 per cent by weight of the tannery sludge in a mixture with domestic sewage sludge could be digested, provision has been made for pumping the tannery solids into the two existing digesters. Except for some foaming during the first two weeks of the month that has elapsed since the experiment was started, no significant change has yet occurred in digestion conditions.

It is not anticipated that any serious difficulty will be encountered as long as the tannery sludge remains substantially below the indi-

* A. L. Elder, formerly Assistant Sanitary Engineer, Wisconsin State Board of Health.

cated 40 per cent tannery-sewage sludge limit. Since 1932 another plant, shown in Figure 2, equipped with separate sludge-digestion facilities has been satisfactorily taking care of relatively small amounts of tannery solids in combination with the sewage sludge. The tannery

FIG. 2.—Pre-treated tannery and cannery wastes are conveyed to this plant by separate pipe lines, being mixed with the sewage ahead of the primary clarifier and in the dosing tank of the trickling filter, respectively. Large solids are removed by a rotary screen unit at the tannery and the cannery wastes are pre-treated by fine screening and chemical precipitation.

wastes are given preliminary treatment through a 20-mesh rotary screen unit to remove hair and fleshings prior to junction with the sewage at the inlet of the primary clarifier at the municipal plant.

With the renewed interest in chemical precipitation for municipal sewage treatment, and with successful sludge disposal by filtration and incineration, it is possible that a number of the larger industrial cities will be in a better position to cope with sewages containing fluctuating amounts of trade wastes known to be inimical to biochemical treatment processes. Chemical precipitation methods should also prove particularly helpful in taking care of problems created by seasonal industries.

CANNERY WASTES

Canning is a typical seasonal industry. The major problem in Wisconsin is occasioned by pea-canning wastes, the period covered by the pack being only about six weeks. As a result of experimental work started in 1926 at Poynette,[2] 40 plants such as shown in Figure 3, employing chemical precipitation for cannery wastes, have been installed in Wisconsin. Ferrous sulphate and lime are used as precipitants, pea-canning wastes requiring 3¼ pounds and 7¼ pounds, respectively, per 1,000 gallons. Alum and lime are used in the treatment of kraut-canning wastes.

Where essential, additional treatment for the effluents from these plants has been provided through municipal sewerage systems. Special studies[3, 4] have shown that trickling filters will provide a high degree of treatment for the canning wastes, provided the filters are not overloaded. The results of these studies appear to be borne out by certain data recently obtained, as follows:

During the past year two new municipal sewage treatment plants designed to handle large volumes of canning plant wastes have been placed in operation. Plant No. 1 in a city with a population of ap-

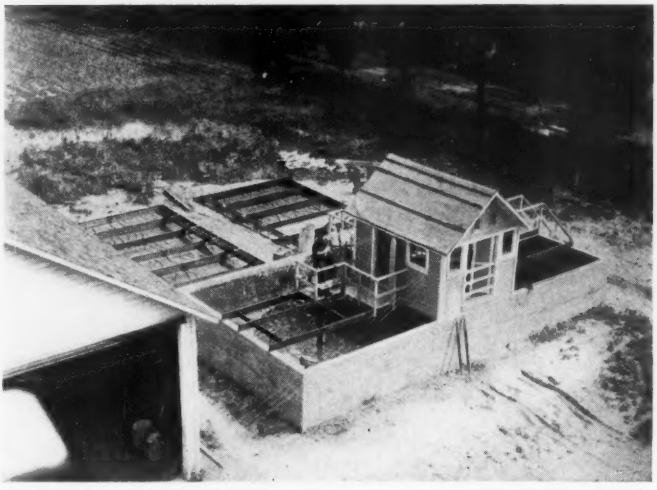

FIG. 3.—Chemical treatment plant for cannery wastes. After passage through a 40 mesh rotary screen, the wastes are treated with lime and ferrous sulphate, using a fill and draw process.

proximately 2,000, consists of separate-sludge digestion, trickling filter, secondary sedimentation, followed by sand filters. The cannery in this city has a continuous-flow chemical precipitation plant for preliminary

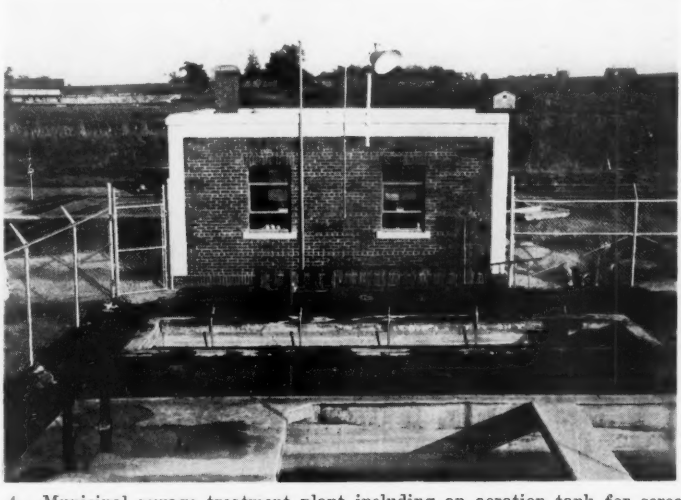

FIG. 4.—Municipal sewage treatment plant including an aeration tank for screened cannery wastes, shown above. After fine screening at the cannery, the wastes are aerated (two hours detention period) prior to final treatment with the settled domestic sewage on a trickling filter.

treatment, following which the waste is pumped into the municipal sewerage system for further treatment. Plant No. 2 is located in a village with a population of approximately 1,300, and consists of separate sludge digestion, followed by a trickling filter and secondary sedimentation. The only preliminary treatment at the factory given the canning wastes is screening, following which the waste is discharged into a separate sewer leading to the municipal treatment plant. At the treatment plant the waste is aerated for a period of about two hours (see Figure 4), following which it is mixed with the settled domestic sewage and pumped to the filter.

In both cases the quantity of canning waste is in excess of the domestic sewage load during the pea-canning season, and about equal during the other packs. Results of analyses obtained with plant No. 1 are listed in Table I, and for plant No. 2 in Table II.

TABLE I.—*Treatment Results—Municipal Sewage Before and After Combination with Cannery Wastes After Chemical Precipitation at Factory. Results of Analyses in Parts Per Million*

Test	Raw Sewage	Tank Effluent	% Reduction by Tank	Rock Filter Effluent	% Reduction by Rock Filter	%—Overall Reduction through Rock Filter	Second Tank Effluent	% Reduction	%—Overall Reduction through Second Tank	Sand Filter Effluent	% Reduction by Sand Filter	%—Overall Reduction through Sand Filter
Domestic Only												
Susp. Solids.....	50.0	40.0	20.0	34.0	32.0	20.0	16.0	68.0	53.0	6.0	62.5	88.0
5 Day B.O.D.....	67.6	61.9	8.4	17.9	73.5	71.2	15.4	77.0	13.9	5.1	66.9	92.4
Lbs. 5 Day B.O.D..	139.1	127.4	8.4	36.8	73.5	71.2	31.7	77.0	13.9	10.5	66.9	92.4
Total Organic N..	4.0	3.0	25.0	2.0	50.0	33.3	1.0	75.0	50.0	1.0	0.0	75.0
Free Ammonia....	1.5	1.3	13.3	0.5	67.0	61.5	0.5	66.7	0.0	0.4	20.0	73.2
Domestic and Pea-canning Wastes												
Susp. Solids.....	168.0	160.0	4.8	288.0	71.4+	80+	92.0	45.0	68.0	32.0	65.2	81.0
5 Day B.O.D.....	536.0*	727.0*	35.5+	346.0	35.4	52.4	310.0	42.1	10.4	121.0	61.0	77.2
Lbs. 5 Day B.O.D..	1050.0	1425.0	35.5+	678.0	35.4	52.4	608.0	42.1	10.4	237.0	61.0	77.2
Total Organic N..	33.0	27.5	16.6	21.0	36.3	23.6	14.5	56.0	31.0	6.0	58.6	81.9
Free Ammonia....	22.0	32.0	45.4+	21.9	0.4	28.4	17.4	20.9	20.5	7.0	59.7	55.5
Domestic and Beet-canning Waste												
Susp. Solids.....	320.0	204.0	36.0	176.0	45.0	13.7	76.0	76.0	57.0	16.0	79.0	95.0
5 Day B.O.D.....	1087.0	998.0	8.2	274.0	75.0	72.5	163.0	85.0	40.5	40.3	75.0	96.2
Lbs. 5 Day B.O.D..	1007.0	924.4	8.2	253.8	75.0	72.5	151.0	85.0	40.5	37.3	75.0	96.2
Total Organic N..	32.0	29.0	9.0	21.0	34.4	27.6	14.0	56.0	33.3	5.0	64.2	84.4
Free Ammonia....	17.1	21.5	26.0+	14.4	15.8	33.0	13.7	14.0	4.9	5.3	61.3	69.0

* Note: Power off for 3 hours during collection period. Primary treatment only during time. Samples not collected.

DISCUSSION OF RESULTS AT PLANT NO. 1

Prior to the canning season this plant was found to be producing an over-all efficiency of 92.4 per cent based on reduction of 5-day B.O.D., and 88 per cent based on removal of suspended solids. At the time of this test the plant had been operating only a short time, and probably had not reached its maximum efficiency. A test during the pea-canning season indicated 77.2 per cent reduction based on 5-day B.O.D., and 81 per cent reduction of suspended solids. During the beet-canning season the plant accomplished a reduction of 96.2 per cent based on B.O.D., and 95 per cent based on suspended solids.

TABLE II.—*Treatment Results—Domestic Sewage Before and After Combination at the Municipal Plant with Screened and Aerated Cannery Wastes. Results of Analyses in Parts Per Million*

Test	Raw Sewage	Tank Effluent	% Reduction by Tank	Raw* Canning Wastes	Aerated Canning Wastes	% Reduction by Aerator	Computed Mixture	Filter Effluent	% Reduction by Filter	Second Tank	% Reduction by Second Tank	%—Overall Reduction by Filter and Second Tank
Domestic Only												
Susp. Solids	148.0	108.0	27.0					120.0	11.1+	14.0	88.1	87.0
5 Day B.O.D.	171.0	128.0	25.0					41.0	68.0	23.0	43.8	82.0
Lbs. 5 Day B.O.D.	198.7	148.7	25.0					47.6	68.0	26.7	43.8	82.0
Domestic Only												
Susp. Solids	208.0	76.0	63.4					54.0	29.0	16.0	70.5	79.0
5 Day B.O.D.	286.0	236.0	17.5					46.0	80.5	39.0	15.2	83.2
Lbs. 5 Day B.O.D.	190.8	157.4	17.5					30.7	80.5	26.0	15.2	83.2
Domestic and Tomato Waste												
Susp. Solids	156.0	84.0	46.1	244.0	200.0	18.0	138.0	52.0	62.3	32.0	38.4	76.8
5 Day B.O.D.	350.0	333.0	4.9	379.0	356.0	6.1	344.0	66.0	80.8	57.0	13.6	83.4
Lbs. 5 Day B.O.D.	212.5	202.1	4.9	199.0	186.0	6.1	388.1	74.7	80.8	64.5	13.6	83.4
Total Organic N.	8.5	5.5	35.2	10.5	8.5	19.0	6.9	4.0	42.0	3.5	12.5	49.3
Free Ammonia	27.4	31.5	29.1+	5.3	5.0	5.7	19.2	2.6	86.4	2.3	11.5	88.0
Domestic and Pea Waste Both Through Aerator												
Susp. Solids	327.0	200.0	46.2	112.0	148.0	32.2+		284.0	92.0+	60.0	78.8	59.4
5 Day B.O.D.	780.0	757.0	2.9	495.0	523.0	5.6+		180.0	65.5	58.0	67.8	89.0
Lbs. 5 Day B.O.D.	723.1	701.7	2.9	773.2	816.9	5.6+		281.2	65.5	90.6	67.8	89.0
Total Organic N.	43.5	29.5	32.1	15.5	20.5	32.2+		15.0	26.8	6.0	60.0	70.7
Free Ammonia	31.0	36.6	18.0+	13.3	13.0	2.3		15.8	20.5+	11.6	26.6	10.7
Domestic and Pea Waste												
Susp. Solids	380.0	180.0	52.6	192.0	148.0	22.9	161.2	132.0	18.0	40.0	69.6	75.0
5 Day B.O.D.	977.0	688.0	29.6	1513.0	1505.0	0.5	1167.4	206.0	82.5	284.0	37.8+	75.7
Lbs. 5 Day B.O.D.	1285.0	905.4	29.6	2827.8	2812.8	0.5	3718.2	656.1	82.5	904.5	37.8+	75.7
Domestic and Tomato Waste												
Susp. Solids	248.0	180.0	27.4	288.0	264.0	8.3	220.5	84.0	61.8	48.0	42.8	78.0
5 Day B.O.D.	305.0	185.0	39.3	252.0	185.0	26.6	184.1	22.0	88.0	22.0	0.0	88.0
Lbs. 5 Day B.O.D.	188.5	114.3	39.3	145.4	106.7	26.6	221.0	26.3	88.0	26.3	0.0	88.0
Total Organic N.	21.8	21.5	1.4	13.0	12.6	3.1	17.2	1.6	90.6	1.4	12.5	91.8
Free Ammonia	21.4	21.7	1.4	1.88	1.73	8.0	12.1	0.47	96.0	0.66	25.3+	94.3

* Note: Cannery wastes had been passed through a screen at factory and conveyed to the aeration unit at the municipal plant through an industrial sewer.

It is interesting to note that with a loading of one pound of B.O.D., to 20 cubic feet of rock, the per cent reduction by the filter and secondary tank amounted to 57 per cent, and with one pound to 40 cubic feet, 85 per cent; while the sand filter reduced the B.O.D. of the secondary tank effluent 61 per cent and 75 per cent, respectively.

DISCUSSION OF RESULTS AT PLANT NO. 2.

Several tests made at Plant No. 2 during the canning season indicated no appreciable reduction in B.O.D. as the result of aeration. However, the dissolved oxygen content of the aerated wastes was sufficient to maintain a considerable D.O. content in the mixed waste and sewage as applied to the filter. During the past season no difficulty

was encountered with pooling on this filter, although the mixed waste was being applied at a rate in excess of five million gallons per acre per day during the canning season.

With a loading of one pound of B.O.D. per 11 cubic feet of rock the reduction by the filter and secondary tank was 75.7 per cent. With a loading of one pound of B.O.D. to 49 cubic feet of rock, the reduction was 88 per cent. The above results indicate that there may be a distinct advantage in aeration of the canning plant waste prior to treatment on a rock filter. This statement is based on a very limited number of chemical tests. It is hoped to secure additional analyses during the next canning season, following which more definite conclusions may be warranted.

Special studies have also been conducted to determine the feasibility of using the activated-sludge treatment process in modifying or removing pollutional substances from pea- and corn-canning wastes after preliminary screening and mixing with domestic sewage. While the pea-canning operations extended over a relatively short period during the 1934 pack, sufficient data were obtained to indicate that an excessive load was being placed on the sewage treatment works (see Figure 5),

FIG. 5.—Activated sludge plant where experiments have been conducted in the treatment of a sewage containing cannery and packing plant wastes.

and that additional aeration or pre-treatment facilities for the cannery wastes would be essential for satisfactory results. Data obtained during the corn-canning season further substantiated initial results. When the loading of the sewage works was such as to increase the sludge index (Mohlman index) [5] above 200 the oxygen content of the effluent decreased, and bulking and other operating difficulties were encountered. Studies of the batch digestion of mixtures of cannery

waste solids and equal portions of raw and activated sludge in carboys, suitably equipped for measurement of gas and sampling of sludge, indicated that up to 20 per cent by weight of pea cannery solids, there was very little change in the digestion characteristics; but with an increase in cannery solids above 20 per cent, there was an increase in acidity during the early period of digestion and in the per cent of carbon dioxide in the gas produced.

Milk Plant Wastes

Milk plant wastes, particularly cheese factory wastes, frequently offer difficulties in the operation of municipal sewage treatment works. Acid-producing constituents have interfered with sludge digestion and have seriously reduced treatment efficiencies. Studies conducted in Wisconsin[6] and elsewhere having shown that trickling filters are effective in removing such constituents before milk wastes are discharged into sewerage systems, installations similar to that shown in Figure 6

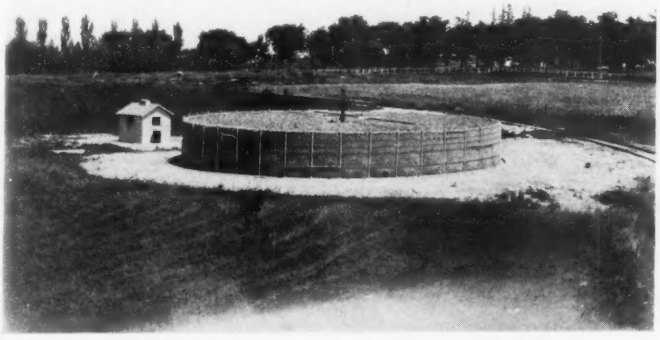

Fig. 6.—Trickling filter system for the treatment of milk plant wastes.

are being made to overcome some of the existing difficulties. Whey from cheese factories, being a very strong waste, it utilized where possible for hog and poultry feeding purposes on the farms of factory patrons, but further effort needs to be directed toward taking care of the situations in the larger communities where the whey problem has often been "solved" by dumping the waste into the municipal sewerage system.

Conclusion

Sufficient information has been presented to show the general procedure being carried out in Wisconsin in reaching solutions for industrial waste problems. It is believed that there is an increasing

appreciation of the fact that the effect of industrial wastes on the treatment of municipal sewage must be given careful study by municipal officials, by industrial organizations and by sanitary and municipal engineers, both designers and operators, if progress is to be made. A clearer understanding of problems involved can be gained by an interchange of information and experiences. General knowledge of the difficulties that have been encountered and of the methods that have been adopted to solve these problems should result in future economies in municipal sewage treatment, in a better understanding of industrial waste treatment responsibilities, in a more wholesome relationship between municipalities and industries, and in the recognition by sanitary engineers of the necessity of making thorough studies, in each community, of the character of industrial wastes and the probable effect of these wastes on sewage treatment. It is essential that careful and unbiased consideration be given to each local problem.

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Editorial

GARB AND SUE—A BEDTIME STORY

Once upon a time there were two children, Garb, a boy, and Sue, a girl. Garb and Sue lived in adjoining back yards, for they were too dirty to live with their mother, Mrs. Age. Garb and Sue were so filthy, smelly and foul that their stepfather, Mr. Civitas, would not keep them in a respectable home, but banished them to the back yard, where they lived in dilapidated, grimy hovels. Their yards were separated by a fence; on one side lived Garb, on the other, Sue.

In Sue's yard there was a pool of water. Mr. Civitas was very proud of this pool, and occasionally drew water from it to drink, but Sue used it to wash her dirty face and clothes, and therefore the water wasn't very good for drinking purposes.

Garb never washed. He groveled in dirt and usually burned his dirty clothes, dry-cleaned his face, and sent his left-over food to a hog farm. Garb was just a nuisance—he didn't want to clean up, because it was such an effort.

Now the children had a well-meaning uncle, whose name was Mr. Santy Eng. He began to be interested in the children and started to reform Sue. He taught her to wash her face; he adjusted her diet so her digestion and health improved; he cleaned her clothes with chemicals, aerated them and disinfected them. Soon he noted such an improvement in Sue that he tore down her shack and built an attractive, scientifically-designed house for her home. Her face and clothes were now so clean that the pool became a credit to the back yard and could be used more and more for play, for fish, or even for drinking purposes. Sue's only duty was to keep the pool clean.

Meanwhile Garb grew up into more of a problem. His piles of dirty clothes increased, his face became more greasy, and his odor spread. Uncle Santy decided he must do something about Garb. Instead, however, of keeping Garb in his own back yard, Uncle Santy broke an opening in the fence and let Garb in with Sue. This was too bad for Sue, who had tried hard to improve her yard and to keep her pool clean, but now Uncle Santy was putting Garb into her yard. Uncle Santy also supplied Garb with a grinder, with which he could grind up his dirty clothes and left-over food, and dump the dirt into Sue's pool. Uncle Santy thought this would be a great help for Garb, and, since two are said to be able to live as cheaply as one, why keep the children apart? Sue cried because Garb had been thrust upon her, but Uncle Santy assured Mr. Civitas that Garb's new grinder would practically eliminate the dirt from his back yard, and anyway, a little more dirt in Sue's pool would never be noticed.

Meanwhile Sue tried hard to keep the pool clean, but Garb dumped so much of his dirt in it that Sue felt rather discouraged. She gradually became a little soiled and sour-tempered by her close contact with Garb, so her mother no longer could feel proud of her daughter's appearance and surroundings.

Although Garb now unloaded much of his dirt in Sue's yard, his own yard failed to show much improvement, for it was still littered with cans, bones, ashes and rubbish that wouldn't go through his grinder. Uncle Santy had good intentions to pave Garb's yard, so that it could be cleaned more easily, but the paving material was in use elsewhere, so this plan failed. However, Garb got rid of most of his dirt in Sue's yard, so many observers were led to believe that at last Garb had been reformed and regenerated. The trouble he had brought to Sue was overlooked, because her health and appearance had undergone such an improvement, due to the care lavished on her, that she was considered able to carry the additional burden without complaint. What if she did become sick a little more often? What if her pool was dirtier and the fish died? Didn't she have some new toys, and didn't her uncle tell her that she should feel proud to have helped in Garb's regeneration?

However, Mrs. Age didn't like the way in which the pool was soiled, and Mr. Civitas discovered that, counting the cost of cleaning Garb's yard, and with more doctor's bills for Sue, he was paying as much as before for the upkeep of the children; furthermore, the slight improvement in Garb's appearance was obtained only at the expense of Sue's happiness.

Uncle Santy was therefore advised to make a further study of Garb's problem, in some other way than unloading the dirt in Sue's yard. Uncle said he would put Garb back in his own yard, and that he would help him, by advice and research, to emulate Sue's scientific development. This decision put new life into Sue and soon her pool was clear and sparkling, there were no rotten tomatoes in her yard, and her doctor's bills showed a great decrease. She looked at Garb's plight sympathetically, however, and promised to help him solve his problem of how to grow up to be a credit to his parents.

Moral: Look before you leap from the frying pan into the fire.

F. W. M.

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CALIFORNIA SEWAGE WORKS ASSOCIATION

Eighth Annual Meeting

Palo Alto and San Francisco, Sept. 23–24, 1935

Concurrently with the first two days of the Annual Meeting of the League of California Municipalities, the California Sewage Works Association held its Eighth Annual Meeting at Palo Alto and San Francisco. From 8:00 A.M., Monday, September 23, until 5:30 P.M., Tuesday, September 24, the meeting extended through the daylight hours and part of Monday evening.

Following registration at the beautiful Community Center Building at Palo Alto the members proceeded to the relatively new Palo Alto subsidence and separate sludge digestion plant, for inspection of the works. Returning to Palo Alto the group convened in technical session, discussed standing committee reports and listened to H. O. Banks' presentation of a paper descriptive of the Palo Alto Plant, the reasons for its selection, its operation features and costs.

Luncheon was tendered by the Board of Public Works of Palo Alto and served in the Community Center dining room. Three of the Stanford faculty members joined the members at luncheon and spoke informally.

From Palo Alto the members proceeded by automobile caravan to an inspection of the sewage disposal plant at San Mateo, now under construction, the recently completed Burlingame plant, the San Francisco Jail plant, the site of the proposed Richmond-Sunset plant in Golden Gate Park and the Golden Gate Park plant. At the latter location the members dispersed to re-convene at 7:00 P.M. at the St. Francis Yacht Club for the annual dinner.

Mayor Pomeroy of South Gate addressed the dinner audience and spoke of the position which an organization such as the California Sewage Works Association should occupy in the governmental structure of the State. He stressed the importance of sound and reliable technical advice to city officials charged with the responsibility of selecting materials of construction and types of public works, and drew attention to the fact that there is a broader horizon for Association members than that of personal advantage, brought about by contact with other members or by discussion of advanced ideas or individual unsolved problems.

Mr. Pomeroy's inspiring address was well received and prompted a desire on the part of Association members that a fuller understanding of the group knowledge and resources of the California Sewage Works Association be made available to the policy-determining officials of the State and its subdivisions, in order that such officials be encouraged to rely upon the Association for guidance in those civic affairs touching upon its activities.

Mr. Pomeroy's suggestion of a discussion of the California Sewage Works Association's aims, objectives and achievements before the Mayor's and Councilmen's Section of the League met with the approval of the Association's governing board.

Tuesday A.M., at the William Taylor Hotel, San Francisco, the Engineers and Street Superintendents Section of the League met with the Association. City Engineer John Casey, of San Francisco, and his assistant, Ben Benas, outlined what is in prospect for the City and County of San Francisco in the way of advanced sanitation and sewage disposal. Mr. Casey touched upon the financial steps involved and the system now in operation. He related the careful study by his office and the Board of Consulting Engineers which has led to the adoption of the plan of sewage disposal. Mr. Benas enlarged upon the engineering and design studies. Of the Engineers' Consulting Board, Messrs. Hyde and Kennedy were present, and each contributed in clearing up points of discussion. Messrs. Reynolds and Eddy of the Consulting Board were unable to attend. All are members of the C. S. W. A.

Mr. J. W. B. Blackman, City Engineer of Long Beach, discussed sewer pipe disintegration in his city, illustrating his address with views of Long Beach sewers which have been or are being destroyed by the

action of oxidized hydrogen sulphide gas. He related the measures which are being taken by the city to retard the destructive action in existing sewers and eliminate it in future installations. Mr. Blackman's well-illustrated presentation left no doubt in the minds of his audience as to the importance of current knowledge in sewer design and maintenance if the sewer be expected to exist more than a few years in place.

The importance of foresight in the design of sewage plant facilities was detailed by Wm. F. Ingram of the San Joaquin County Health Department in a discussion of the overloaded plants of the San Joaquin area. Industrial wastes, unanticipated and unforeseen by the short-sighted and inexperienced, many times account for extensive overloading of facilities, resulting in gross pollution and menace to public health and welfare. Mr. Ingram cited the case of Stockton, in particular, where a sewage treatment plant designed for the normal population of the city was now attempting to treat sewage from a population equivalent to three times as great, with poor success.

Dr. Richard Pomeroy, Research Chemist, Los Angeles County Sanitation Districts, illustrated a new departure used in the detection of hydrogen sulphide in sewage and described the value of the test in treatment processes and sewer maintenance.

The Tuesday afternoon session of the Association was devoted to a symposium on sludge-gas engine construction and operation and a presentation of plant operation problems by operators.

In the gas engine symposium, C. F. Tennant, Chief Operator, Los Angeles County Sanitation Districts' plant, related experiences in four months' operation of a 200 H. P. gas engine at his plant. The engine is used for pumping 18 m.g.d. of plant effluent through a 36-inch force main, 20,000 feet long, to final disposal. The gas engine accomplishes a net saving of $300 per month.

S. A. Greeley of Chicago contributed a paper descriptive of early efforts in the use of sludge gas for internal combustion engine fuel. The paper progressed to practice in England and Germany and finally detailed the installations in the United States. Mr. Greeley quoted widely from plant data over the world, set out operation costs and stated information calculated to inform those contemplating such use, of the preliminary information desirable and the probable cost and savings in operation.

A. K. Hegeman, sales engineer of Smith-Booth-Usher Company, Los Angeles, read a paper dealing with sludge-gas engine development from the manufacturers' angle. He pointed out features to be avoided as well as those to be sought in such equipment, discussed good and bad methods of operation and their reflection in operating costs, and concluded by specifying a number of "don'ts" for operators if they desire success with sludge-gas engines.

In addition to describing conditions which led to the selection of a sludge gas engine for the sewage plant of Ontario, California, A. Burt, City Engineer, presented a complete and composite picture of the new

plant, which is of the activated-sludge type, departing considerably from conventional design.

H. O. Banks of Palo Alto related experience at the Palo Alto plant with sludge-gas engine operation.

William Berg, San Bernardino, Fred West, Stockton, and A. B. Shearer, Marin County Sanitary District No. 1, took part in the plant operators' symposium. Each described his plant process, stressed its shortcomings, spoke of its advantages and proposed means whereby improvements in process and operation might be gained.

The operators' remarks were of particular interest to designers and, it must be said, left no doubt in the minds of the latter that a thorough knowledge of plant operation might be a beneficial prerequisite to their professional efforts.

The meeting concluded with the election of the following officers for 1936:

President: A. M. Rawn, Assistant Chief Engineer, Los Angeles County Sanitation Districts.

First Vice-President: E. A. Reinke, Research Engineer, Bureau of Sanitary Engineering, California State Dept. of Public Health.

Second Vice-President: R. F. Goudey, Sanitary Engineer, Department of Water and Power, City of Los Angeles.

Board of Directors, 1940: J. F. Byxbee, City Engineer and Executive Officer, Board of Public Works, Palo Alto.

Member, Board of Control: Harold F. Gray, Sanitary and Hydraulic Engineer, Berkeley.

Hold-over officers are:

Director, 1936: L. B. Reynolds, Professor of Hydraulic and Sanitary Engineering, Stanford University.

Director, 1937: W. A. Allen, Superintendent, Pasadena Sewage Disposal Plant.

Director, 1938: A. G. Darwin, Editor, San Francisco.

Director, 1939: J. F. Smith, Engineer, Great Western Electro-Chemical Corp., San Francisco.

Secretary-Treasurer: F. D. Bowlus, Resident Engineer, Los Angeles County Sanitation Districts, 202 Law Building, Los Angeles.

Ninety-five members were registered at the session and the average meeting attendance was eighty.

F. D. Bowlus,
Secretary-Treasurer

A PLANT OPERATOR'S PROBLEMS

By Fred West
Stockton

I don't believe there is a city in the State of California where, at the present time, industries are overloading the sanitary disposal facilities as in Stockton. Prior to the advent of Mr. Ingram and his investigation of the industrial waste problem of Stockton, I was operating a steam plant for the city and conditions at that plant were very bad. I was transferred to the Southern Disposal Plant upon its completion and felt that Mr. Ingram's investigation would be to the advantage of the city and would clear up certain disposal problems. Prior to taking over the operation of the Southern Disposal Plant I had an opportunity to inspect the construction, and to speculate upon how the plant would operate upon completion. The power plant is very nicely arranged and it was apparent that I was going to have plenty of power and pump capacity but knowing the industrial waste problem at the old plant, particularly with respect to solids content, I began to wonder what I was going to do with that condition in the new tank. I could see no means of disposing of all of the accumulated solids which I knew would appear in the industrial wastes. The engineers who designed the tank, did it without much reference to the manner in which it should be operated, sacrificing good operation to economy of construction, apparently thinking that after it was completed they would be "out of the picture" and any further troubles would be my business.

Well, I made quite a study of the tank and after a careful inspection, remarked to myself: "Well, here's where you are going to have to do a lot of figuring and studying and testing if this thing is to operate successfully." The top of the tank was decked with a multitude of doors, for what purpose I have never been able to understand. The city officials, in their wisdom, decided that they wanted me to use only half of the tank capacity. I remarked at the time that if I could get by using the full tank capacity, both the city officials and I, as well as the city of Stockton, should be very thankful. But they said to use only half so I commenced operation that way, with an initial flow of about a million and a quarter gallons per day. In a few days I saw some of these trick doors on the top of the tank commencing to bulge. The largest part of the gas chamber was overflowing so I placed the other half of the plant in service and nearly broke my back opening doors. There was no provision made for a fresh water supply on top of the tank, so I installed a fresh water system and began hosing down the vent chambers, which was practically a continuous operation, opening and closing doors all the time. This latter got to be too much of a job so I commenced removing doors and before long I had quite a pile of them surrounding the plant. About this time the city engineer came down to investigate and asked what was going on. I showed him and said, "Send me down a carpenter to build a walk over the top of the

tank so I won't fall in, and also to build a stairway up to the tank top so that I can get back and forth between the pumps and the tank runway ten or twelve times an hour without wearing myself out doing it." I have a considerable regard for engineers but you can see what they'll do to you if they don't have to operate their own structures.

I don't know who was responsible for getting me on this program and I intend to speak my mind clearly while I'm up here on my feet. In my experience the plant operator's complaints are not given enough attention by those in power. Those responsible for the administration of the plant delight in passing him the works. He must figure out his difficulties for himself and with particular reference to industrial wastes coming into the plant, must determine the party who is guilty and then he must work out the problem to his own best advantage and that of the city.

This new plant was an Imhoff tank installation and I didn't know much about it except, like Will Rogers, what I read in the papers and in some books. From what I knew I figured out a system of operation and then tried my best to get some information from the many important gentlemen who looked the plant over. Their reply was, in effect, that the same condition was existing in all other plants and to just figure the thing out for myself. I asked some of them why they wrote books on the subject to tell the other fellow how it was done and then couldn't tell me anything. They had no reply. I got an honest opinion from Professor Reynolds when I asked him what others do in like circumstances. He replied, "Nothing, except what you are doing—so just continue."

I kept continually after the city engineer to bring an individual to the plant to whom I could put my questions and get helpful and intelligent answers. I told him I would like to have the gentleman who is the designer of this tank come down here someday. One day he telephoned stating, "Your wish is granted. Dr. Karl Imhoff is going to be in California and I'll bring him down if he comes up here." I was delighted and thought, "Here's where I get some real answers." The day the Doctor was going to pay me a visit I was all prepared, with everything cleaned up ship-shape. My plant was operating fairly well at the time and when the Doctor came I told him I'd heard a lot about him and I was glad to have him here to look over this situation. We went up to the top of the tank. I was anxious to find out from Dr. Imhoff how to stop foaming. He said "In some plants, pumping sludge into the gas chambers has eliminated foaming but it will never work here because the sludge accumulates on top of the fresh sludge and you have just twice as much." That was the Doctor's contribution at a time when my plant was operating better than it ever had before.

Well, all this time I kept after the administration to do something with the industrial wastes because of the amount of solids in the float chamber. I took out and readjusted scum boards, doors, and the like and could see all the time that I was doing a great amount of no good.

I wasn't getting any help in curtailing industrial flows but I had plenty of pumping capacity so I jammed the sewage through and let nature take its course. About this time Mr. Ingram arrived on the job, said there would be a thorough examination of the diluting body of water, as well as the plant conditions, and probably we would get an addition in capacity. Sure enough there was quite a stir in the administration and they made application to rebuild or add to the structures. I hope that it will be only a matter of time when conditions will be improved and I will be in a position to invite you all to a plant that I would not be ashamed to have you look at.

The first industrial contributor to overload our facilities was a fibreboard factory and I concluded that whenever there is material left that won't make fibreboard it must be pretty bad. I was getting quite a collection of that. I told the city engineer that the fibreboard company was using the sewage plant for the disposal of a lot of material not fit to make fibreboard. The condition was found to be true, was stopped, and I wish you could see the collection of waste material they now have in a field next to their factory. The next trouble was due to the establishment of a cheese factory. I commenced to get all the whey, or whatever it is that you can't make cheese out of. There was no doubt about where this waste came from. It was almost too much for me. I called the city engineer and he said it couldn't be the cheese factory. I told him to come down and see. Standing on top of the tank, we discussed the relative merits of Limburger and California cheese; finally went down to the cheese plant and found that their day shift was carefully collecting the waste material and putting it in cans which the night shift dumped into the sewer as a means of disposal. We stopped that practice.

Following this I got collections of oils, grease and grit. Installation of traps in garages, grease racks and a few other devices, as a result of an ordinance, helped this condition considerably. A lot of others interfered, but the final one, not so long ago, was a cannery company which makes tomato sauce. Tomatoes are ground up and the liquids are extracted from the solids and the seeds. The residue goes into the sewer. A month after the commencement of this operation the gas vents accummulated so much that they were 18 inches above the deck of the tank. I have had a man working two weeks removing this collection at the rate of a wheelbarrow load every five minutes, and I have quite a collection of tomato skins at the plant site.

In closing, I extend an invitation to you all to come up and see a real plant as soon as pending improvements have been made.

Reviews and Abstracts

H. W. Streeter

FACTORS IN THE DESIGN OF SEWAGE DISPOSAL WORKS

By H. C. Whitehead and F. R. O'Shaughnessy

The Surveyor, **88**, 403–07, 433–39 (October 18, 25, 1935)

In this interesting and comprehensive paper the authors trace the gradual development, largely British, of biological methods of sewage purification, show that these processes have been slowly evolved by selection and that consequently they are very firmly established. Moreover, because these methods exemplify the results of long experience with the natural phenomena of changes in organic matter in sewage, they are likely to remain as standard practice for an indefinite time. However, there is justification for examining these basic principles in the light of changes in the composition and increase in strength of sewages being brought about by industry and the resulting need for careful design of sewage treatment devices to meet the requirements of such situations.

No review of sewage treatment could be written, of course, without due acknowledgment of the monumental work of the Royal (Iddesleigh) Commission on Sewage Disposal and the conclusions and views of the Commission are freely quoted. Also, the Commission concentrated on treatment methods for the settled sewage liquor rather than on procedures for the separation and disposal of the solid matters and the present paper follows this plan. However, the effectiveness of treatment of such liquors by the newer activated sludge process is often more limited than by the percolation beds then in vogue and, without prejudice to the newer procedure, the authors make the point that " when designing a plant to deal with any particular sewage, the closest and most careful study of the composition, qualities and behavior of the sewage under known conditions should be made before the selection of the method of treating it is decided on."

Chemical Treatment.—The authors' views on this method of sewage treatment coincide with those expressed by cited American authorities, namely, that these processes have not yet emerged from the experimental stage and that " the role of such processes must be the usual well known one for the relief of the load on oxidation plants, the reduction of pollution, or for partially treating difficult trades wastes and sewages."

Functions of Sedimentation Tanks.—In addition to the generally accepted function of sedimentation tanks to remove suspended solids, the authors stress other important ones. These are:

a. To average the variations in strength of the sewage,
b. To balance inequalities in the rate of flow of sewage,
c. To provide time for self purification.

To accomplish these purposes, longer detention periods are essential, even up to 12 or 15 hours, although for balancing the load to be passed on to the oxidation process, tanks with a variable capacity must be used. One objection to these long detention periods—development of septic action—can be minimized by proper design to avoid stagnant water zones and to provide cleaning operations to check unnecessary fermentation.

Data are presented to support the claim for natural purification—biochemical oxidation—of the sewage liquor in the tank, said to amount to as much as 50 per cent, and to demonstrate that such bacterial purification is held up by chlorination. Such self-purification demonstrates the value of longer sedimentation time in effecting oxidation which otherwise must be accomplished later and at higher cost either in activated sludge plants or bacteria beds.

Strength of Sewage.—The effort of the Royal Commission Report is discussed, to compare the work done by various types of oxidation plant. The formula proposed for this purpose by Dr. McGowan and Mr. Frye in the Fifth Report is cited, namely:

$$\left.\begin{array}{l}(\text{Ammoniacal nitrogen} + \text{organic nitrogen} \times 4.5)\\ + (\text{volatile suspended solids} \times 2) - \text{nitric nitrogen} \times 3)\end{array}\right\} = \left\{\begin{array}{l}\text{Weight of oxygen required to oxidize the impurities in 100,000}\\ \text{parts of the liquor.}\end{array}\right.$$

An important finding in this connection and still of value is that the dilution of strong sewage with an equal volume of clean water will permit filtration at twice the rate of the undiluted liquor, but that the effluent of the diluted liquor will be more highly purified. A graph shows that this same principle applies to effluents from the activated sludge process, although as the purification rate for the weaker liquor declines more rapidly, a larger size plant will be needed for the greater volume of the weaker liquid.

The value of mathematical treatment of oxidation rates is discussed in some detail and the methods of approach suggested by Mr. Tatham who worked for the Royal Commission and by Mr. Theriault of the U. S. Public Health Service are reviewed with full appreciation of their limitations as applied to the complex biological factors involved. It is frequently apparent "that something more than existing simple empirical rules is necessary for guidance when setting out not merely to design plant but more important still to decide which type of plant shall be used."

The Avidity of Sewage Liquors for Oxygen.—Appreciation of the rapidity with which oxygen is absorbed by sewage liquors is essential for the proper design and successful operation of biological sewage treatment plants, particularly of the activated sludge type. Graphs are given which illustrate the effect upon the rate and extent of biochemical oxygen demand by such factors as increase in sewage strength, age of sewage, strong industrial sewage, partial treatment by activated sludge and dilution. The point is made that in an activated sludge plant this avidity for oxygen may be greater than the aeration facilities are able to supply and that under such conditions the process ceases to function. The rate at which oxygen is supplied in activated sludge plants is, therefore, the most important limiting factor in the application of this process to the complete treatment of strong sewages and industrial wastes. In such cases partial treatment may be used to considerable advantage. In this connection the authors suggest that "bulking" of sludge is caused frequently by this high, unsatisfied avidity for oxygen of the sewage liquor which prevents proper biological action and thereby interferes with floc formation.

Miscellaneous.—As stated in the conclusions, "The later portion of the paper is devoted to a detailed history of the development of the bacteria bed and some account of the authoritative contributions of the Iddesleigh Commissioners as to the detailed performance of such beds.

"Reference is also made to the development of other oxidation methods—the activated sludge processes, and the use of activated sludge for giving partial treatment to a sewage liquor.

"Problems presented by storm water, aerial nuisance and its elimination, humus tanks, means of control, etc., are dealt with, and the practical importance of proper attention to the appearance and best lay-out of plant and buildings is discussed.

"The paper is accompanied by twelve diagrams from which the figures in the text have been prepared."

J. K. Hoskins

SURVEY OF RIVER TEES (PART II)

Water Pollution Research, Technical Paper No. 5

By W. B. Alexander, B. A. Southgate and R. Bassindale

British Water Pollution Research Board, 171 pp. (1935)

This report deals with the results of a comprehensive chemical and biological investigation of the River Tees estuary covering a period of four years. The object of

the survey was to obtain data on the effects of sewage and trade effluents on the river and the extent to which these wastes should be purified to prevent serious pollution.

The tidal section of the river from Yarm down to Stockton flows through an agricultural country, but below Stockton passes through a densely populated industrial area. In the 7-mile stretch from Stockton to Cargo Fleet, the combined wastes from 280,000 population are discharged. Large numbers of migratory fish attempting to pass through the estuary are killed each year, and the value of salmon and sea trout fishery has declined.

Together with the general tidal movement of the whole body of water up and down the estuary are other movements. Fresh water flows downstream mainly in the upper layers and salt water upstream in the lower strata. The middle stretch of the estuary is thus stratified. The estimated time of flow through the estuary is 2.5 days in wet weather and 6 days in dry weather. Substances carried in the upper strata reach the sea more rapidly and substances in the lower strata less rapidly than indicated by these average times.

As a result of decomposition and oxidation of sewage and industrial effluents discharged into the river, the central part of the estuary is usually deficient in dissolved oxygen. The rate of oxidation is higher in summer, when on some occasions the dissolved oxygen may be as low as 5 per cent of saturation, which is sufficient to support fish life. Observations and experiments have indicated that about 60 per cent of the reduction in D.O. in the River Tees estuary is due to sewage and about 40 per cent to industrial wastes.

Near the mouth of the estuary, marine fauna and flora are abundant and at Yarm fresh water forms are numerous. In the central zone, particularly just below Stockton, there are few marine or fresh water organisms, their smallest numbers coinciding with the region of maximum pollution. Surveys have shown that in all three estuaries the scarcity of marine and fresh water organisms is due largely to unsuitable tidal conditions.

The most important of the industrial effluents discharged into the Tees are those from by-product coke works. The main constituents of these wastes are cyanides and phenolic tar acids. Approximately 2 tons of tar acids and 1 ton of cyanide are thus discharged daily as an average. Cyanide is more toxic than tar acids, a concentration of 0.1 to 0.2 p.p.m. being sufficient to kill fish in one hour. Systematic observations have indicated that cyanide has been the main cause of death of large numbers of fish in the River Tees during recent years. This substance has been detected in the estuary in concentrations sufficient to kill fish. Gills of smolts, picked up in a dying condition, have had the brighter color characteristic of cyanide poisoning. This conclusion was an important step in dealing with the problem, as cyanide poisoning had not been suspected previously as being the cause of the death of fish.

Several methods of treating effluents containing cyanide were studied, including treatment with lime and waste liquid from local galvanizing works. In this case a 1 per cent dilution of the untreated waste killed fish in a few minutes, whereas the treated waste in the same dilution was found innocuous after 24 hours. From the work relating to coke oven effluents, it has been concluded that the discharge of such effluents to the river could be greatly reduced in quantity, and possibly avoided, by modification in the methods of cooling and washing coke oven gas and by using the waste liquids for quenching coke. Future installations of coke oven will be so designed that appreciable quantities of polluting liquids need not be discharged.

Sewage pollution of the estuary can be reduced by treatment or by discharging the sewage into the sea at a point some distance from the shore.

The report contains many illuminating tables and charts and an appendix dealing with methods of analysis. It is an important contribution to the literature.

H. W. STREETER

THE PRESENT STATUS OF SEWAGE PURIFICATION IN SOVIET RUSSIA

From the Report of Prof. S. N. Stroganoff

By Dr. R. Wieners and Dr. H. Bach

Gesundh.-Ing., 58, 448 (1935)

In May, 1934, thirty papers on sewage treatment were presented before a group of scientists in the Academy for Communal Science in Moscow. Self purification of streams, anaerobic digestion of sludge and the activated sludge process were discussed and the following Russian treatment plants were described:

The biological purification plant at Detzkoje Selo (Leningrad) was built in 1906 and was designed for the treatment of 2,774,000 gallons from a population of 30,000. The sewage is well diluted with ground water and has an average B.O.D. of 200 p.p.m. The temperature of the sewage in winter reaches 40° F.

The plant at Tula, which consists of two grit chambers, four pairs of Imhoff tanks, two trickling filters with fixed distributors and artificial sludge dewatering beds, in 1933 handled a daily sewage flow of about 2,180,000 gallons from 70,000 inhabitants or 31 gallons per capita. The results of treatment are satisfactory in the summer but during the winter, the trickling filters are overloaded.

At Simferopol, the treatment plant consisting of two Travis tanks (with colloiders), two trickling filters with fixed distributors, two secondary settling tanks and two final trickling filters (Dunbar type) was built in 1925–1929. The daily sewage flow in 1933 was 660,500 gallons from a population of 25,000. The purification has been satisfactory even during the canning season when the sewage load is doubled.

Since 1889 Odessa has used broad irrigation of sewage. An average sewage flow of about 4,755,000 gallons (10.5 gallons per capita) is treated on 2828 acres, of which about 700 acres lie fallow. With doses of 1070 to 1800 gallons per acre per day, depending upon the season, excellent yields of vegetables are obtained. A sandy layer, 20 to 30 inches thick, is sufficient to guarantee satisfactory purification with the climatic conditions of Odessa.

The experimental work of the Moscow Sanitary District is carried on at the Koschuchowo plant which treats a daily sewage flow of about 10 to 13 million gallons in three independent groups of units. The equipment consists of:

1. Settling tank (Dortmund type)
2. Aeration tanks for activated sludge (30 minutes)
3. Reaeration for the activated sludge (80 minutes)
4. Secondary settling tank for activated sludge (Dortmund type)
5. Aerofilter (Artificially aerated trickling filters treating 30 gallons aerated sewage per cubic foot of slag daily)
6. Chlorinating apparatus for disinfection of the effluent
7. Biothermic tanks (Beccari type) for screenings
8. Separate sludge digestion tanks, heated to 77–86° F. for the sludge of tanks 1 and 4
9. Land prepared for drying digested sludge
10. Compressors, pumps, motors, boilers, etc.

The proposed treatment plants for Charkow will be designed for a population of 1,625,000 (present population 650,000) with a daily sewage flow including industrial wastes of 103,000,000 gallons (present flow 11,889,000 gallons). The sewage will be treated by the activated sludge process and digested sludge will be dried on sand beds for use as fertilizer. Since the plant effluent is discharged into a river, the flow of which is negligible as compared with the amount of sewage, chlorination will be used.

G. P. Edwards

WASTES FROM THE MARGARINE INDUSTRY

By Commissioner Glaser, Clave

Gesundh.-Ing., **58**, 254 (1935)

The waste from the actual production of margarine contains oil and fat particles, is turbid from the milk residues, has a sour odor and is relatively small in volume. However, large amounts of waste result from the treatment of the raw materials and from the various cooling processes. The raw oil contains small amounts of free fatty acids which are removed as soap by treatment with caustic. The soap, which is removed by mechanical means and by washing, is hydrolyzed with sulphuric acid. Unless the process is carefully supervised, the wastes may sometimes be acid.

The liquid vegetable oils are solidified by treatment with hydrogen which is produced from water gas. The very hot wash water obtained in purifying the hydrogen contributed indirectly to the corrosion of the sewer.

An investigation in 1920 showed that the sewer into which the wastes were discharged was being attacked. This sewer was well constructed of masonry and completely tight but the mortar joints, especially in the crown and upper walls, were considerably corroded. The damage was caused by the sulphate and sulphuric acid content of the waste and by hydrogen sulphide. The sulphate and free sulphuric acid attacked the mortar and formed calcium aluminum sulphate. The fact that most of the disintegration of the mortar took place in the crown of the sewer and on the walls above the water line indicated the presence of a corrosive gas, such as hydrogen sulphide. The discharge of the hot water into the sewer containing domestic sewage encouraged the formation of hydrogen sulphide.

Further damage to the sewer was prevented by neutralizing the acid wastes, by cooling the hot water to prevent the formation of hydrogen sulphide and by the removal of vapor and gases from the sewer, through adequate air shafts.

Before treatment the waste is very warm, yellow and contains fine oil drops which separate out on the surface. It smells very rancid and has a strong acid reaction.

After treatment the waste is slightly yellow and contains traces of oil. Its odor is slightly rancid and the reaction is still slightly acid.

The analyses of the waste, before and after treatment, are shown in the following table:

	Before Treatment	After Treatment
Total SO_3	903 p.p.m.	693 p.p.m.
Combined SO_3	546 p.p.m.	595 p.p.m.
Free SO_3	357 p.p.m.	98 p.p.m.
Oil content	680 p.p.m.	280 p.p.m.

It is assumed that the free acid in the treated waste is neutralized by dilution with other water inside the plant.

G. P. Edwards

THE DEVELOPMENT OF SEWAGE TREATMENT IN FISH PONDS

By Director Th. Falck, *Detmold*

Gesundh.-Ing., **58**, 6 (1935)

Biological purification in fish ponds consists in the working over of soluble and finely divided organic matter by innumerable small organisms which serve as food for fish. The largest installation of fish ponds is at Munich where the sewage from 700,000 persons is treated on about 550 acres. Generally, an acre of pond can treat the settled sewage from 800 to 1200 persons and may produce 1600 pounds of healthy carp a year.

Sewage fish ponds have not been more commonly used because either the required area of ground or sufficient dilution water was not available. The load on the ponds

has been successfully increased to 1600–1800 persons per acre. If there is sufficient head the available dilution water can be added to the highest pond and the effluent from this pond used to dilute the influent to the next pond below. Ground water, cooling water and the effluent from trickling filters have all been used for diluting purposes. When broad irrigation is employed in the vicinity of overloaded ponds, the sewage, at periods of greatest concentration, can be distributed on the land.

Since selling the fish in the fall and rebuying in the spring creates unfavorable market conditions, it is generally more economical to keep them through the winter in fresh water.

Young fish grow better in shallow ponds and live longer in low concentrations of oxygen than do old fish. Water plants may supply oxygen during the summer, but when they die in the autumn they seriously interfere with fish culture. Although ducks should eliminate weeds, it is not always profitable to raise them on sewage ponds, as they frequently eat the fish and may require grain.

The use of fish ponds requires a thorough knowledge of fish culture since a slight error in operation, especially during the winter, can be disastrous.

G. P. EDWARDS

COURT DECISION ON SEWAGE DISPOSAL

Mississippi Supreme Court, Division B; Hodges et ux. v. Town of Drew, 159 So. 298; Decided Feb. 11, 1935

Public Health Reports, **50**, 43, 1501–2 (October 25, 1935)

An action was brought by the plaintiffs, husband and wife, against the town of Drew to recover damages for injuries to the plaintiffs' health and comfort and to their land, alleged to have been caused by the improper and negligent maintenance by the defendant of its septic tank. The trial court, at the conclusion of the evidence, directed the verdict for the defendant, and the plaintiffs appealed.

The evidence for the plaintiffs showed that the town had permitted the septic tank to fall into disrepair to such an extent that sewage overflowed and contaminated the surrounding land and the waters of a nearby lake. The septic tank and the lake, in part, were situated on the plaintiffs' farm. Offensive and nauseating odors were emitted by the overflowing sewage. The town sought to justify the directed verdict on the grounds (*a*) that the evidence failed to show that the plaintiffs suffered any peculiar or special damage on account of the maintenance of the nuisance not common to the general public, and (*b*) that in the construction and maintenance of the waterworks system, including the septic tank, the town was in the exercise of one of its police powers, that of conserving the public health, which was a governmental function, in the exercise of which, although wrongful, the town was not liable for damage to property. The supreme court rejected both of these contentions, reversed the judgment, and remanded the cause.

H. W. STREETER

FEATURES OF THE NEW NORTHSIDE SEWAGE TREATMENT WORKS OF DURHAM, N. C.

BY WILLIAM M. PIATT

Water Works and Sewerage, **82**, 337 (October, 1935)

Durham has recently put into operation an activated sludge plant with separate sludge digestion that has several unusual features. The new plant serves the north side of the city where practically all the industries contributing industrial wastes are located. These wastes, mainly from textile mills, present a difficult problem. Some of them are highly caustic, with oxygen demands ranging up to 6000 p.p.m., and many are highly

colored. In addition to these wastes a residential population of approximately 30,000 people is tributary to this plant. An agreement was made between the city and the industries under which the latter agreed to construct such pretreatment works as were necessary to equalize the quantity and strength of their wastes and to reduce the loadings on the municipal system to meet standards determined by the city. Several of these pretreatment plants are already in operation and it is expected that all of them will be in service by January, 1936.

The water supply and sewage disposal are operated as a single utility in Durham. This consolidation of services has resulted in several operating economies. One very interesting result has been the possible interchange of power between the hydroelectric plant at the impounding reservoir and the sewage treatment plant. The sewage treatment plant has a 50,000 cu. ft. capacity gas holder in which gas from the digesters is stored. All of the gas produced is used for the generation of electric power, the waste heat from the gas engines being used to heat the digesters. An outdoor substation is connected through a four-mile transmission line to the line between the city hydroelectric plant and a substation of the Durham Public Service Company. This connection serves not only as a stand-by connection for the sewage treatment plant, but also allows the interchange of power at any time between the sewage plant and the city's hydroelectric plant. During certain seasons of the year the hydroelectric plant is operated only the minimum number of hours daily necessary to fill the service reservoirs. During shutdown periods, the sewage plant supplies the necessary power for lighting and minor operations at the hydroelectric plant, drawing upon the stored gas if necessary. This power, if needed, can be restored to the sewage plant during periods of operation of the hydroelectric plant, thus allowing the reserve capacity in the gas holder to be restored. Later it is planned to perform a similar lighting service for the water filtration plant. At the present time, the sewage plant is producing sufficient gas to provide power for all plant operations and for lighting service at the hydroelectric plant without requiring any return of power. The quality of the gas produced can be closely watched by means of a Precision recording calorimeter installed in the laboratory which may be connected to any of the digesters by a separate gas header. This calorimeter record is a direct indication of the relative amounts of methane and carbon-dioxide being produced and will detect unfavorable conditions developing in the digesters long before they can be detected by the conventional pH determination. Digested sludge is dried upon sand beds 50 ft. square. Four of the ten beds are covered with an unusual roof of corrugated glass supported by bow string trusses. The structure has no side walls to obstruct ventilation. A Link Belt conveyor spans all of the beds. Sludge is loaded onto the conveyor by hand and delivered to trucks in the driveway along one side of the beds.

The aeration tanks are equipped with a novel type of air diffusers placed lengthwise of the center of the tank at the bottom. Each air diffuser unit of galvanized cast iron contains eight diffuser plates set in a vertical position, four on each side, with a ½-inch air space between. Air is fed from a chamber below the plates which is an integral part of the unit. The units are connected with 4-inch flanged fittings forming a continuous air header below the plates. The vertical position of the diffuser plates serves as an automatic regulator giving a uniform distribution of air throughout the length of the tank. The vertical position facilities cleaning the plates as nothing is deposited on them except such growths as readily form. These growths are easily removed if washed with a firehose as soon as the tank is emptied and before they have dried out.

R. S. SMITH

EXPERIENCE WITH CHLORINATION OF ACTIVATED SLUDGE

BY E. E. SMITH

Water Works and Sewerage, **82**, 362 (October, 1935)

During the summer of 1934, the Lima, Ohio, activated sludge plant experienced a great deal of difficulty with bulking of sludge accompanied by a marked increase in the

number of fungus filaments in the aeration units. All previously described remedies were attempted, such as increased air, variation in amount of sludge returned, ferric chloride and lime. None of these remedies gave beneficial results, with the possible exception of heavy doses of lime. Finally, in October, chlorination of the return sludge was tried. At this time only one tank of chlorine was used without careful control, but the results were so promising that a solution-feed chlorinator was installed and put into use on November 2nd. Seven days after the start of chlorination, fungus filaments were absent from the sludge, the per cent of sludge by volume in the aeration tank mixture had dropped from 75 per cent to 16 per cent and the sludge index had risen from 0.42 to 2.50.

Apparently the ratio of p.p.m. of chlorine applied to each per cent of suspended solids in the return sludge is a governing factor in the use of chlorine for removal of fungus filaments, because during a second trial in December, no removal was obtained when that ratio was below 1.00. On several occasions since December, chlorine has been successfully used in reducing the number of filaments. Complete removal of the filaments has not been attempted in these later experiments, nor has it seemed necessary.

The use of chlorine is considered to have effected a saving of between $470 and $1,650 in this 4.5 m.g.d. plant in 8½ months, due to the saving in power used for air compression. The author states that bulking may be eventually expected when the air-sewage ratio is reduced below 1.00 to 1.25 cu. ft. per gallon, but with the use of chlorine, the air requirements should not exceed an average of 0.90 cu. ft. per gallon. It is felt that this last figure is amply high, because the air consumption has been as low as 0.62 cu. ft. per gallon daily average and as low as 0.78 cu. ft. per gallon monthly average during chlorination. Without the ability to correct sludge bulking so readily and effectively with chlorine such low applications of air would have been unwise and impracticable.

R. S. Smith

WATER SUPPLY AND SEWAGE DISPOSAL AT SINGAPORE, STRAITS SETTLEMENTS

By I. W. Mendelsohn

Water Works and Sewerage, **82**, 371 (November, 1935)

Singapore is on an island at the extreme southern end of the Malay peninsula, very near the equator. The climate is hot and humid with an average rainfall of 99.6 inches. The population of 475,000 comprises natives of nearly every Asiatic nation plus many other races.

The sewage from the various parts of the city, averaging 4.62 m.g.d., is pumped by electrically driven centrifuged pumps located in five stations to the Sewage Disposal Works, which were completed in 1930. The plant has coarse screens, detritus tanks, 32 Imhoff tanks, 55 circular trickling filters, humus tanks, sludge drying beds and experimental units. All the sewage passes through the detritus and Imhoff tanks. About 75 to 80 per cent of the Imhoff tank effluent is treated in the trickling filters and the remainder is partially purified in a bio-flocculation unit. The effluent from this unit, except for a small amount that goes to an experimental filter bed, is mixed with the effluent from the trickling filters and the combined flow is then passed through the humus tanks before being discharged. Sludge from the humus tanks is dried on sludge beds and that from the other tanks is dumped on special grounds.

The Imhoff tanks provide a detention period of 2.65 hours at maximum dry-weather flow. The direction of flow through these tanks is reversed weekly. Sludge with an average moisture content of 95.5 per cent is drawn off in small quantities at frequent intervals at the rate of 1177 gallons per million gallons of sewage treated. Experiments on sedimentation of sludge by the addition of 3.5–4.5 p.p.m. of aluminum sulphate to detritus tank effluent or by agitation of detritus tank effluent with compressed air gave little effect. The trickling filters are 6 ft. deep and 100 ft. in diameter and are dosed by

revolving distributors at rates of 40 to 90 gallons per cu. yd. per day. They are filled with broken granite or coral. At first, ponding of the upper 12 inches was a source of considerable trouble. This layer is now washed in place by turning it over and hosing with a strong jet of clear effluent pumped from the humus tanks. The humus tanks, which give two hours of settling, are provided with upward flow filters of small lumps of coral at the tank outlet to prevent the surface scum, which appears soon after desludging, from passing off into the effluent. About two-thirds of the humus tank sludge which is dried on the sand beds is disposed of to the public for tennis courts, gardens, etc., and the rest goes to the dump grounds with the sludge from the detritus and Imhoff tanks.

Much experimental work has been done on bio-aeration, bio-flocculation and sludge digestion. A bio-aeration tank was constructed with 10 channels having a total length of 1365 feet and a capacity of 198,000 gallons at 4 ft. depth. Mechanical agitation was provided by 9 ft. diameter paddle wheels on two lines of shafting. This unit treated an average of 188,000 g.p.d. of Imhoff tank effluent, but could not handle more than 240,000 g.p.d. The best results were obtained with an addition of 15 per cent of return sludge. Purification seemed to proceed even when the sludge was bulking. Chlorine added to the sewage entering the tank at varying rates up to 36 p.p.m., adversely effected the biological life in the sludge. General operating results were unsatisfactory.

This unit was subdivided to obtain a four channel flocculation tank of 76,200 gallons capacity and a six channel sludge reaeration tank of 114,000 gallons capacity. Commencing in October 1930, the average quantity of Imhoff tank effluent treated in this unit was 853,776 g.p.d. Settled activated sludge in the amount of 1.62 per cent of the sewage flow was added to the sewage entering the tank and the average detention period was but 1.92 hours. This resulted in a reduction of 75 per cent in suspended matter and 50 per cent in oxygen absorption. The effluent from this unit was applied to a 20 ft. diameter experimental trickling filter, similar in every respect to the main filters. Results indicate that for approximately equal results, the partially purified sewage from the bio-flocculation unit can be put through a trickling filter at a rate nearly four times that for the Imhoff tank effluent.

Tests on intermittent chlorination of Imhoff tank effluent applied to the trickling filters at rates up to 55 p.p.m. of chlorine showed no apparent reduction in ponding nor improvement in the filtrate, but did reduce the odors from the filters.

R. S. SMITH

THE MENOMONEE FALLS, WISCONSIN, ACTIVATED SLUDGE SEWAGE TREATMENT PLANT

By ROBERT CRAMER, JR.

Water Works and Sewerage, 82, 418 (December, 1935)

Menomonee Falls put an activated sludge sewage treatment plant into service in March, 1935. The plant, designed for an ultimate population of 1800, utilizes preliminary settling with separate digestion and mechanical aerators. The aeration tanks provide an aeration period of 4.9 hours, with a return sludge flow of 20 per cent. Sludge return is accomplished by gravity, utilizing the hydrostatic head available between the surface of the liquor in the final settling tank and the depressed surface of the liquor within the orifice cone of the aerator, thus eliminating the power costs of a continually operated return sludge pump. Waste sludge flows are regulated by means of an adjustable overflow pipe. An automatically controlled gas engine, utilizing digester gas, operates a generator which is expected to supply most of the current needed for aeration. The plant is operated by the Village Street Superintendent, who normally spends about an hour and a half per day at the plant, cleaning the bar screen and pumping primary sludge. This is the only work done at the plant other than routine sweeping and cleaning. The aerators are operated only 75 per cent of the time, being controlled by time switches set to a 15-minute cycle.

The plant is not provided with technical supervision and routine laboratory control examinations are not made. Results of a test run of about a week's duration during a period of dry weather flow were as follows:

Sewage Flow (Average)	144,000	g.p.d.
Suspended Solids:		
Raw Sewage	194	p.p.m.
Final Effluent	2.9	p.p.m.
Reduction	98.5	per cent
5-Day B.O.D.:		
Raw Sewage	172	p.p.m.
Final Effluent	3.5	p.p.m.
Reduction	98.2	per cent
Suspended Solids in Mixed Liquor	1280	p.p.m. (Average)
Sludge Index	99	(Mohlman)

At the end of the test period when the mixed liquor suspended solids were 2000 p.p.m., a dissolved oxygen survey was made of the aeration tanks. A substantial amount of dissolved oxygen was shown throughout these tanks. This observation is especially noteworthy because difficulty has been experienced, with many mechanical aerator installations, in maintaining an excess of dissolved oxygen with suspended solids concentrations exceeding 900 p.p.m.

R. S. Smith

MALARIA CONTROL IN THE TENNESSEE VALLEY

By W. G. Stromquist

Civil Engineering, **5**, 771 (December, 1935)

The Tennessee Valley Authority is creating a number of reservoirs with long mileages of shore lines. The area is endemic to malaria, and, within the mile-flight zone of the mosquito, is quite extensive. The problem has been studied in many ramifications, and with results in certain adopted procedures.

Anopheles *quadrimaculatus* breeds on ponded areas. Constant water level, minimum wave action, and the presence of aquatic growths and débris are conditions favorable. Breeding occurs in shallow inshore waters, and is most extensive during early years until a biological balance has been established.

Preventive measures include clearing between low and high water lines; draining of pools that become landlocked during reservoir operation; and stocking waters with top feeding minnows.

In addition, the design and operation should provide for impounding during the non-breeding fall and winter, and should permit of periodic (10-day) fluctuation of water level (1-foot) during the breeding season which, normally, is from July to September. The purpose and effect of fluctuating reservoir levels are to discourage aquatic growths and to strand the larvae where they will die.

The article cited gives a documented comparison between mosquito control by water level fluctuation and by larvicides. The latter includes paris green or oil which is applied mechanically from power boats, or dusted or sprayed manually. The use of aeroplanes for this purpose is being studied, but cost and other data are not yet conclusive.

In the Tennessee Valley, the schedule of operation will provide for fluctuating reservoir levels in rotation and coupled with interchange of load. In this way the prime purposes of the reservoirs will not be affected.

State regulations for mosquito control have been developed by Alabama and Virginia. Regulations aim for biological control, but this must be supplemented by the use of germicides. Infection by malaria has been made the basis for court action.

Frank Tolles

SEWAGE TREATMENT EXPERIMENTS AT ATLANTA, GA.

By M. T. Singleton and G. R. Frith

Civil Engineering, 5, 767 (December, 1935)

A 0.5 m.g.d. experimental plant is being operated at the Atlanta Intrenchment Creek plant to determine whether chemical precipitation ahead of trickling filters would permit an increase to the filter load.

Procedures included the application of chlorinated copperas to Imhoff tank (3-hour detention) effluent and to raw sewage. Ferrous sulphate was chlorinated in the solution line before application to the sewage. The dosed sewage was flash mixed 2-mins., flocculated 30-mins., settled (clarified) 1.45 hrs., and then filtered. Dosage varied 200–600 lbs. per m.g. Trickling filter rates were 4–6 m.g.d. per acre. Some results are given in the following tabulation:

	Normal Operation			Chemical Precipitation		
	Sus. Solids	5-day B.O.D.	Total Red.	Sus. Solids	5-day B.O.D.	Total Red.
Raw Sewage	180 p.p.m.	170 p.p.m.	—	175 p.p.m.	165 p.p.m.	—
Imhoff Tank Effluent	70 p.p.m.	120 p.p.m.	30%	80 p.p.m.	120 p.p.m.	27%
After Precipitation 400 lbs./m.g.	—	—	—	85 p.p.m.	105 p.p.m.	35
Filter Effluent 2 m.g.d./acre	40 p.p.m.	30 p.p.m.	82	—	—	—
Filter Effluent 6 m.g.d./acre	—	—	—	40 p.p.m.	28 p.p.m.	83
Magnetite Effluent	16 p.p.m.	18 p.p.m.	89	—	—	—

The data of the table are from 24-hour composites. Four-hour composites showed lessened peaks of B.O.D. when chemicals were used.

Chemical precipitation to obtain materially greater removals than those in Imhoff tanks required dosing with 700–900 lbs. of copperas per m.g., but improvement of filter performance was independent of clarification and suggested that the benefits from applications of iron showed mainly in the filter itself. (On this point the article refers to early work by Dunbar—*Principles of Sewage Treatment*, Dunbar and Calvert.)

Trial was made of filtering a dosed (300 lbs. per m.g.) Imhoff tank effluent without flocculation and settlement. This carried iron on to the filter in quantity that proved toxic.

Intrenchment Creek sewage varies in pH, normally between 6.9 and 7.4, but at times to exceed 9.0. Acid adjustment was found costly and difficult. Laboratory work showed that 100–150 p.p.m. CO_2 reduced pH to 6.2. An application of this method was made by burning Imhoff tank gas vent gas, and by blowing the flue gases to the sewage through porous tubes. Flue gases carried 4–6 per cent CO_2 and were used at the rate of 6 c.f.m. per m.g.d. of sewage flow. Submergence of the porous tubes was inadequate, but pH was reduced from a range of 6.9 – 8.4 to 6.8.

Conclusions for Intrenchment Creek sewage and conditions were (1) Chemical precipitation of raw sewage is preferable to and less costly than the treatment of presettled sewage; (2) Adjustment of pH to the acid side is the more effective; (3) Adjustment of pH with CO_2 is practicable, facilitates flocculation, and lessens cost for chemicals; (4) Improvement of filter operation is not dependent wholly upon the degree of purification effected by previous chemical precipitation; (5) Iron in small doses makes the sewage more amenable to filtration and, on filter media, enhances purification; (6) Straining or filtering after final clarification is useful with or without chemical precipitation of final effluent.

Frank Tolles

TRADE WASTE TREATMENT PLANT AT BELTSVILLE RESEARCH CENTER, MARYLAND

ANON.

Engineering News-Record, **115**, 787 (December 5, 1935)

Placed in operation July 15, 1935, the plant is designed to handle .4 m.g.d. of mixed trade wastes from a 500 cow dairy creamery and cheese factory, a 200 hog abbatoir, large laboratories and a tannery. With the Center not complete, flows have ranged from .05 to .2 m.g.d. with a maximum raw sewage B.O.D. of 400–500 p.p.m. and an effluent not exceeding 30 p.p.m. B.O.D.

The plant consists of 1¼″ bar screen and duplicate grit chambers, flocculators, primary settling tanks, rotary trickling filters, final settling tanks, heated digestion tanks with floating covers and glass covered sludge drying beds. Chemical feed equipment for lime, copperas and chlorine is provided. Chlorine may be applied ahead of the screen, following the grit chambers or to the plant effluent, with the outlet sewer in this case baffled to act as a contact chamber. The copperas solution, chlorinated in the feed line through a silver tube can be added to either or both halves of the plant ahead of the flocculators. A complete laboratory is provided for control and experimental purposes.

R. W. KEHR

SPRINKLING FILTER REQUIREMENTS IN NEW JERSEY

ANON.

Engineering News-Record, **115**, 753 (November 28, 1935)

The new regulation, adopted November 12, 1935, recommends chemical precipitation where the 5-day B.O.D. of the raw sewage exceeds 325 p.p.m., a means for complete flooding of the filter by sections, and removal of either half or any quarter of the nozzle field from service. Requirements include: 6–9 ft. depth of 1″–2″ stone; underdrain ventilation; 630,000 gallons per acre per day per foot depth maximum dosage rate; 1,100 gallons per minute per acre per foot maximum dosage rate when the 5-day B.O.D. does not exceed 215 p.p.m., and proportionately less for B.O.D.'s over 215 p.p.m.; 20 per cent to 40 per cent filter operating time; one hour minimum detention period in final settling tank; ½ cu. ft. per capita excess capacity for final settling tank sludge if digested, or ¼ sq. ft. per capita of glass covered sludge beds if dried directly; 15 minute maximum dosing cycle; and 1½ ft. minimum net terminal head on nozzles.

R. W. KEHR

THE REVIVAL AND PRESENT STATUS OF CHEMICAL PRECIPITATION

BY M. N. BAKER

Engineering News-Record, **115**, 748 (November 28, 1935)

At the present time, chemical precipitation plants are in operation in 34 cities, eleven others are under construction and 25 plants have been projected. This compares with a total of 3500 municipalities now treating their sewage. The plants in operation or projected are distributed among 27 states, most of them are small and iron salts are being used, alone or in combination in 59 of 66 plants for which data are available. Many of the plants, including some of the largest, either provide only part time chemical treatment or treat sewage high in trade wastes. The revival of chemical treatment is due largely

to lower prices and improved equipment for handling precipitants formerly used and to a growing appreciation of the flexibility of the processes. "All signs point to the construction of hundreds of sewage treatment plants in the next decennium, in which chemical processes will have the share that recent advances fully warrant."

R. W. KEHR

CHEMICAL MECHANICAL TREATMENT OF SEWAGE

V. Sludge Treatment, Factors Governing Choice of Method—Results Obtainable

BY P. B. STREANDER AND M. J. BLEW

Public Works, **66**, 22 (November, 1935)

On open sludge drying beds at Atlanta, Ga., at an average mean temperature of 71°, an average humidity of 68 per cent, and an average monthly rainfall of 3.15 inches, sludge was spadeable in 10 days, increased in concentration from 5 to 50 per cent in 14 days, then to 80 per cent in 30 days. Drying of chemically precipitated fresh sludge on drying beds was practiced to some extent in earlier chemical precipitation installations.

Vacuum filters have operated on conditioned sludge in actual installations at rates of 12–14 pounds of dry solids per square foot per hour, and for average conditions a design figure of 10 pounds is probably safe. Centrifuging of sludge is not only practical but may be preferable to vacuum filtration although there are not now sufficient data on which to base conclusions covering the use of centrifuges. Digestion is practical with an iron sludge but questionable with an iron lime sludge.

Process patents in chemical sewage treatment can usually be circumvented and there are usually available alternate designs of patented equipment and methods of treatment.

R. W. KEHR

THE PATENT SITUATION IN SEWAGE TREATMENT

BY PAUL HANSEN

Public Works, **66**, 13 (November, 1935)

Patents which are valid and useful and for which reasonable royalties are asked, do not cause much difficulty and the wide range of methods and equipment available make it possible to avoid or circumvent patents for which royalties, excessive enough to affect the economy of the process, are charged. Patents such as the septic tank and activated sludge patents which are unexpectedly upheld in the courts cause the most difficulty. A larger group, and one to which more attention should be paid by the designing engineer, are those in which the royalty is included in the price of equipment. The patent situation in sewage treatment is becoming more complicated and in cases of doubtful validity of the patent, or excessive royalty for its use, the employment of a competent patent attorney may be advisable.

R. W. KEHR